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PRELIMINARY SCREENING OF FUEL CYCLE AND BY-PRODUCT MATERIAL LICENSES FOR EMERGENCY PLANNING

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ABSTRACT

This report summarizes work done for the U.S. Nuclear Regulatory Commission as part of a program considering the need for and appropriate level of emergency response planning at fuel cycle and by-product material facilities. The purpose is to (1) provide a base of technical information for identifying and ranking those facilities for which the need for emergency response planning and preparedness should be further considered, and (2) perform an initial screening of licenses issued by NRC. A data base containing the radionuclide possession limits for each license was developed. Dose estimates for a unit (1 curie) release of each of the radionuclides in the data base were calculated. To account for the variability in weather, distributions of doses were estimated for a full range of meteorological conditions. As requested by NRC, doses at the 99th percentile of the distribution were used. An initial screening analysis was performed for the approximately 9400+ licenses by comparing the estimated 99th percentile dose for a postulated release of a fraction of the licensed possession limit to the dose levels suggested in the Environmental Protection Agency's Protective Action Guides.

Using relatively conservative assumptions in the screening analysis, all but at most a few hundred licenses were found to have estimated doses below the Protective Action Guide levels. The few hundred identified in this initial screening should be further evaluated using realistic assumptions and site-specific information to establish the need for, appropriate level and extent of, and potential effectiveness of emergency response planning and preparedness beyond that currently required.

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EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) is in the process of determining whether any fuel cycle or by-product material licensees should be required to develop and implement emergency response plans for providing further protection of the public beyond that now required for responding to accidental releases of radioactive material. For those facilities at which emergency planning and preparedness are found to be needed, regulations concerning the nature, extent, level, applicability, and potential effectiveness of these planning efforts need to be developed. The purpose of this study is to (1) provide NRC with a base of technical information for identifying and ranking those fuel cycle and by-product material facilities for which the need for additional emergency planning and preparedness should be further considered, and (2) perform an initial screening of the licenses issued by NRC. The general approach is first to screen the facilities by estimating the possible offsite radiological dose that might result from postulated releases of a fraction of the licensed inventory quantity and to compare this hypothetical dose estimate to dose levels that have been determined to warrant the consideration of emergency protective actions. It is expected that most licenses allow an insufficient quantity of radioactive material to warrant the need for emergency planning beyond that now required. Licenses which exceed the dose criterion in the initial screening should then be further evaluated using realistic assumptions and site-specific characteristics.

The principal goal of this program is to develop and perform an initial screening analysis of the some 9400+ licenses issued directly by the NRC. Secondary goals include development of information and data for use in succeeding stages of the evaluation process for specific licenses and facilities, and development of methods and data for use in the preparation and evaluation of additional emergency response planning and preparedness efforts.

Pursuant to these goals, the principal efforts in this project were divided into the following tasks:

1. Development of a comprehensive library of dose estimates (dose at selected distances, expressed as rem per curie released) for radionuclides appearing in the possession limit data base.

2. Compilation, from the NRC license docket file, of the radionuclide possession limit data for each license for input into a computer data base containing this information.

3. Development and application of a computer program for screening of the radionuclide possession limit data to identify those licenses which might exceed the dose criteria and for which emergency planning and preparedness should be further considered.

4. Development of procedures for estimating the size of potential emergency planning zones for the immediate plume exposure pathways. For long-term ground exposures, a method is presented for estimating the extent of contaminated land areas.

The library of dose estimates for each radionuclide was developed from calculations using a slightly modified version of the CRAC2 computer code (Ritchie et al., 1983a; 1983b). CRAC2 was selected because it calculates distributions of doses over a full range of meteorological conditions and allows flexibility in the description of the atmospheric transport and dispersion. The calculations considered (1) the atmospheric transport and dispersion of a 1 curie release of each radionuclide; (2) the exposure of a hypothetical individual at selected distances from the release point via three exposure pathways: external exposure to the plume (cloudshine), inhalation of material from the plume, and exposure to contaminated ground (groundshine); and (3) the resulting dose equivalent (dose commitment) at each selected distance.

There are over 20,000 licensed fuel cycle and by-product material facilities in the United States. Approximately half are licensed directly by the NRC Office of Nuclear Materials Safety and Safeguards (NMSS). The other half are licensed directly by individual states currently numbering 26. Reactors of all kinds (power, research, critical assemblies, etc.) are licensed separately by the NRC Office of Nuclear Reactor Regulation and are not considered in this study.

Because of the very large number of licensees and the variety of radionuclides, configurations, possession limits, applications, building types, and so forth, a detailed analysis of the conditions particular to each license is not possible for the initial screening. Consequently, so as to provide guidance that may be applied to the broad range of licenses, a general and simple (i.e., "generic") atmospheric transport and dispersion model has been used. CRAC2 uses the standard Gaussian-plume dispersion model and a simple building-wake effect model. The use of more detailed models is not justified by the nature of the application of these results and by the lack of detailed information needed for such models. Thus, for this initial screening analysis, it is appropriate to use generic assumptions for parameters, such as building size, release duration, etc.

In summary, the basic assumptions used in the atmospheric transport and dispersion calculations include a ground-level release, neutrally buoyant Gaussian plume, constant wind direction, and ground-level exposure point. The released material is assumed to be entrained in the wake of the building, which is 25 m wide by 10 m high. Within the constant direction wind field, the plume is assumed to meander, such that the integrated dose is somewhat lower. For the ground exposure pathway, an 8 hour exposure time is assumed, after which the individual is assumed to be removed to an uncontaminated location. These effects are intended to be representative of the conditions that may be encountered at a typical facility. While one single condition or assumption may be nonconservative at an individual facility (in which case the dose estimated here would be too low), the combination of these assumptions are expected to provide realistic or slightly conservative dose estimates.

Variability and uncertainty in local weather conditions can have a large effect on estimated doses and the probabilities of occurrence of such doses. To provide a framework for bounding the effects of varying meteorology, dose estimates were calculated for a full range of meteorological conditions and a frequency distribution was constructed for each radionuclide and for each distance. From these distributions, dose estimates were selected at the desired level of conservatism; in our case, the 99th percentile, as requested by NRC. For randomly distributed accidents, the actual dose would be expected to be lower 99 percent of the time, with a 1 percent chance of being higher. To use an even higher percentile level would lower the confidence level due to an insufficient number of meteorological samples contributing to the high dose/low probability portion of the frequency distribution.

In prior work concerning human exposures to radionuclides, dose estimates were usually expressed in terms of whole body and critical organ doses, based on the dosimetry and modeling concepts described in the International Commission on Radiation Protection (ICRP) Publication-2 (ICRP, 1959). Recently, improved methods for dose estimation were published by the ICRP in Publications-26, -28, and -30 (ICRP, 1977; 1978; 1979a; 1979b, 1980). The principal change is the use of the effective dose equivalent (EDE), which is based on the stochastic risk for each organ or tissue.

Since the screening analysis and subsequent licensee evaluations are concerned with exposures to single (or a few) radionuclides, dosimetry for these individual radionuclides is relatively more important than in the case of reactor accidents involving a very large number of nuclides. Hence, it was felt that dose conversion factors based on the most recent work in the field should be used. For these

reasons, the new ICRP dosimetry concepts and models were implemented as part of this study.

The dosimetric modeling approaches of ICRP Publications-26 and -30 have replaced the total body concept (from ICRP-2) with the effective dose equivalent. The effective dose equivalent is, however, numerically similar to the dose estimates for the total body. Therefore the total body dose limits from the Protective Action Guides may be used to evaluate estimates of the effective dose equivalent. For accidental releases exposing the general public, the range of 1 to 5 rem from the Protective Action Guides for limits on the total body dose (and the effective dose equivalent) is within the exposure recommendations of ICRP Publication-26. This approach appears to be a consistent application of the EPA Protective Action Guides and the new dosimetric approaches of ICRP Publications-26 and -30 (Runkle and Johnson, 1983; Eckerman, 1983).

At higher dose levels (e.g., 5 rem EDE), limits must be placed on exposures to specific organs other than the thyroid. In particular, for a few isotopes the kidney is the limiting organ and for many alpha emitters (and a few others) the bone surface dose is limiting. Tables of organ dose estimates for these are provided.

For thyroid exposures, the limits in the Protective Action Guides are 5 to 25 rem. The principal nuclides are the radioiodines and tellurium that decays to radioiodine. The definition of the thyroid was not modified in ICRP Publication-30, as compared to Publication-2, and therefore the limits in the Protection Action Guides proposed in 1975 (and revised in 1980) are directly applicable.

One of the first parts of this study was to collect, for use in a computer data base, the radionuclide possession limit information that is specified as part of each license issued by NRC. This possession limit data base has been developed over the last 2 years with the assistance of a subcontractor, International Energy Associates Limited, of Washington, D.C. This development effort was part of a separate program funded by NMSS.

The data base used in the screening analysis in this study represents a snapshot of the docket file as of about May 1984. Changes, additions, deletions, etc., to this file are being processed and accumulated as part of a separate NRC program; there are about 200-300 licensing actions processed each month. Eventually, the possession limit data base will be brought up to date and integrated into the on-line, real-time Licensing Management System.

A number of inconsistencies, ambiguities, and errors were found in the initial screenings of the data base. These can generally be classified as follows:

- Stable, naturally occurring nuclides.
- Naturally occurring nuclides with very long half-lives.
- Unrealistic nuclides.
- Very short lived nuclides, without corresponding parents.
- Single nuclide of mixture: The principal example is U235, without specifying the U234 fraction, which usually dominates the inhalation hazard.
- Possession limit specified with too many (eight or more) significant digits.
- Nuclides which the NRC does not have the statutory authority to regulate (isotopes of actinium, protactinium, etc.).

Over time, license reviews and inspections should resolve and/or correct most of these cases.

The vocabulary used for material descriptions in the data base is very large. A thorough review and simplification of the terminology used for the possession limit descriptions, so as to identify a minimum set needed for the Licensing Management System and the licenses, would significantly enhance user comprehension, and reduce learning time and data entry error rates. If a simpler and more concise dictionary were adopted, a descriptive field could be added to provide any supplemental information that might be appropriate or important. Such a system would be easier to use and understand. This work is in progress under a separate NRC program.

The central basis for the initial evaluation of a licensed facility is that the estimates of dose at a selected distance arising from postulated accidents do not exceed exposure guidelines. In simple terms, the dose to an individual is a product of (1) quantity of material involved, (2) release fraction, and (3) the unit dose estimate for the nuclide considered. Since several dose criteria are used (effective dose equivalent, and thyroid, kidney and bone surface doses), the ratio of the estimated dose to the respective criterion is a measure of the potential hazard. For licenses with multiple nuclides, the sum of the individual ratios is the corresponding measure. This can be expressed as:

$$\sum_{\substack{\text{all}\\ \text{radionuclides}\\ i}} \frac{(Qpl)_i\ (RF)_i\ (Ds)_i}{(Dc)_i} \leq 1 \qquad (6.1)$$

where

Qpl = licensed possession limit

RF = release fraction

Ds = dose estimate for a specified unit release

Dc = exposure dose criterion

and wherein the sum is less than one for releases which would not exceed the criteria. If the sum exceeds one, then, based on the assumptions used, the accidental exposures might exceed one of the exposure criteria. A computer program was written to implement this screening method. Algorithms for processing the isotopes in group medical licenses and broad licenses are included.

For the initial screening, a simple set was chosen that is an extension of the Federal Register set. The nuclides are organized into six groups, based on general estimates of potential volatility:

1.	Volatile gases	H3, AR, KR, XE
2.	Volatile, combustible	C, P, S, I
3.	Semivolatile	BR, RU, TE, HG, PO
4.	Inert metals	CO60, TA, W, OS, RE, IR
5.	Neutron source materials	PU238, PU239, AM241
6.	All Others	All other nuclides

Separate release fractions for nonsealed source forms and sealed sources were assigned as follows:

		Release Fractions	
	Group	Non-SS	SS
1.	H3, AR, KR, XE	1.0	1.0
2.	C, P, S, I	0.5	0.5
3.	BR, RU, TE, HG, PO	0.1	0.01
4.	CO60, TA, W, OS, RE, IR	0.01	0.0001
5.	PU238, PU239, AM241	0.01	0.0005
6.	All other nuclides	0.01	0.001

For the reasons stated above, it should be recognized that these release fractions are assigned parameters in the screening analysis.

For nonsealed source forms of radionuclides, the following table lists the number of licenses for which the dose projections exceed the criteria:

	1 rem EDE	5 rem EDE
Sum > 1	186	134
> 10	99	79
> 100	56	45
> 1000	32	21
> 10000	17	14

If the accumulated conservatisms in the screening analysis assumptions were a factor of 10, then about 80 to 100 facilities would be in the "further evaluation" category. Other results of the screening analyses are presented in Chapter 6.

As part of the safety evaluation for a facility and the consideration of additional emergency response planning and preparedness efforts, it is useful to estimate the distance out to which plume exposure doses or ground contamination might exceed selected levels and for which the implementation of protective actions may be warranted. For the plume exposure pathway, a simple method was developed for estimating this distance given a specification for the size of the release and the threshold dose level (for initiating protective actions), or conversely, for estimating the size of the release given, the distance, and the threshold dose level. This method is based on a simplification of the dose versus distance data for a large number of radionuclides. For the ground contamination case, curves are presented for the resulting ground contamination level for a unit release ($Ci/m^2/Ci$ released) as a function of distance for two values of the settling velocity, which is the dominant parameter in estimating ground contamination levels from passing plumes. These methods and data would be but one part of the overall process of evaluating a facility and establishing the need for and size of emergency planning zones.

The dominant factor for plume exposures is the very short time available after the start of the release for dose avoidance measures to be effective. Immediate and probably unilateral actions by the licensee, such as quick notification of persons located downwind, will be needed. The principal protective action that could be taken by the exposed population would be sheltering; there is insufficient time for evacuation. Responses by other agencies and offsite emergency personnel would not be expected to influence dose avoidance, except for long duration releases and contaminated ground exposures. In-plant accident prevention should not be forgotten as probably the most effective way of reducing or avoiding radiological exposures to the public.

CHAPTER 1

Introduction

The U.S. Nuclear Regulatory Commission (NRC) is in the process of determining whether any fuel cycle or by-product material licensees should be required to develop and implement emergency response plans for providing further protection of the public beyond that now required for responding to accidental releases of radioactive material. For those facilities at which emergency planning and preparedness are found to be needed, regulations concerning the nature, extent, level, applicability, and potential effectiveness of these planning efforts need to be developed. The purpose of this study is to (1) provide NRC with a base of technical information for identifying and ranking those fuel cycle and by-product material facilities for which the need for additional emergency planning and preparedness should be further considered, and (2) perform an initial screening of the licenses issued by NRC. The general approach is first to screen the facilities by estimating the possible offsite radiological dose that might result from postulated releases of a fraction of the licensed inventory quantity and to compare this hypothetical dose estimate to dose levels that have been determined to warrant the consideration of emergency protective actions. It is expected that most licenses allow an insufficient quantity of radioactive material to warrant the need for emergency planning beyond that now required. Licenses which exceed the dose criterion in the initial screening should then be further evaluated using realistic assumptions and site-specific characteristics.

1.1 Background

There are over 20,000 licensed fuel cycle and by-product material facilities in the United States. Approximately half are licensed directly by the NRC Office of Nuclear Materials Safety and Safeguards (NMSS). For the other half, an agreement between NRC and a state provides for licensing directly by the "agreement state," using licensing standards and criteria at least as stringent as those used by the NRC. There are currently 26 agreement states. Reactors of all kinds (power, research, critical assemblies, etc.) are licensed separately by the NRC Office of Nuclear Reactor Regulation and are not considered in this study.

Fuel cycle and by-product material licenses are issued pursuant to Parts 30, 40, and 70 of Title 10 of the Code of Federal Regulations (CFR). Part 40 licenses cover source materials (i.e., uranium and thorium that have not been

enriched), and include uranium and thorium mills, UF_6 conversion plants, fabricators of products containing thorium, or natural or depleted uranium. Part 70 licenses cover special nuclear materials, principally plutonium and enriched uranium. Facilities and activities under Part 70 include fuel fabrication plants, fuel research and development laboratories, and possession of sealed sources. Other isotopes for ancillary or secondary purposes may also be covered under a Part 70 license. Part 30 licenses cover the very broad category of by-product materials and generally encompass any activity not under a Part 40 or 70 license. Facilities and activities for Part 30 licenses include sealed source possession, radiography, administration of medical isotopes, radiopharmacies, radiopharmaceutical manufacturing, sealed source manufacturing, waste warehousing, and university and industrial research and development with radioisotopes. Some government facilities are licensed under Part 30 and Part 70.

The NRC has had for a number of years a Licensing Management System using a computer data base of basic licensee information (name, address, license and docket numbers, expiration date, etc). However, the radionuclide possession limit information is not part of this data base. One of the tasks in this program is to collect and assemble this data into a possession limit data base for use in the initial screenings of all licenses.

The quantities and forms of the radionuclides covered under licenses vary over an extremely wide range. At the small end of the scale are single sealed sources containing a small quantity of an isotope in a chemically inert form. At the other end are very broad licenses for large quantities of many isotopes in any form. As will be seen later, the two largest categories of licenses are for possession of sealed sources, and for possession and administration of radioisotopes for medical purposes.

Onsite radiological contingency plans are currently required of those licensees with sufficiently large licensed possession limits that potential accidents at these facilities may result in: (1) significant offsite doses, (2) serious radiation exposures of workers, or (3) dangerous chemical exposures. The criteria for selection of licensees needing radiological contingency plans are discussed in NUREG-0767 (Fisher, 1981). The format and content of such plans are covered in NUREG-0762 (USNRC, 1981a) and the standard review plan in NUREG-0810 (USNRC, 1981b). Plans may also be required of licensees with sufficient fissile material (U-233, U-235, Pu-239) to require criticality monitors and alarms in accordance with 10 CFR 70.24, and of licensees with large quantities of UF_6.

NUREG-0767 (Fisher, 1981) succinctly summarizes the purposes for having onsite radiological contingency plans:

> Radiological contingency planning is that part of emergency response preparedness contributed by plant operators to assure (1) that plants are properly configured to limit releases of radioactive materials and radiation exposures in the event of an accident, (2) that a capability exists for measuring and assessing the significance of accidental releases of radioactive materials, (3) that appropriate emergency equipment and procedures are provided onsite to protect the workers against radiation hazards that might be encountered following an accident, (4) that notifications are promptly made to Federal, State, and local government agencies, and (5) that necessary recovery actions are taken in a timely fashion to return a plant to a safe condition following an accident.

In determining the need for onsite radiological contingency plans, the evaluation methodology for assessing the possible effects of accidental releases of radioactive materials is based on a consideration of the estimated dose at a selected distance from the release point. The source term used to represent that which might be released following a postulated accident is derived from the quantity of material exposed to the accident environment and a release fraction. For licensing evaluations, the quantity used is the licensed possession limit. The assigned release fraction is from those published in the Federal Register Notice (these Federal Register release fractions are discussed in Section 2.3). A simple reduction (dilution) factor is used to convert the source term quantity to the quantity that would actually expose an individual. A dose estimate is then used to define a "limiting possession limit," which is that quantity of material whose accidental release could lead to exposures above those specified in the Protective Action Guides. The use of limiting possession limits can be ambiguous when considering multiple radionuclides, as there are several assumptions implicit in their derivation; hence they will not be used in this work.

The Environmental Protection Agency has proposed guidelines for protecting the health and safety of the public in their "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents" (EPA, 1980; see also EPA, 1975). The draft guidelines recommend radiation dose levels for determining whether emergency protective actions should be considered following an accidental release of radioactive materials in areas which could be occupied by the general

public. These Protective Action Guides (PAGs) are defined for whole body and thyroid exposures. For the whole body, a projected 1 rem dose for an individual is the threshold for considering the implementation of emergency protective actions. A projected 5 rem whole body dose is the level at which emergency actions are considered necessary. For thyroid exposures, a projected 5 rem dose (to the thyroid) is the threshold level, and a 25 rem thyroid dose is the level at which protective actions become necessary.

Offsite emergency planning and preparedness is now a formal requirement for all commercial nuclear power plants. Written plans detailing the actions to be taken and the involvement of Federal, State, and local governments and agencies are prepared and formally approved by the Nuclear Regulatory Commission and the Federal Emergency Management Agency (FEMA). A joint NRC-FEMA document (USNRC/FEMA, 1980) describes the criteria for preparation and evaluation of the plans. Part of the evaluation is an emergency drill at the site which exercises and tests the effectiveness of the plan.

Emergency planning zones for reactor accidents extend out to approximately 10 miles for the plume exposure pathway and to 50 miles for the ingestion exposure pathway. These zones are much larger than those that might be required for by-product and fuel cycle facilities, due to the very large source quantities of radionuclides involved in reactor accidents.

1.2 Evaluation Methodology

The overall evaluation methodology for considering the need for emergency response plans is an extension and refinement of the general approach used to determine the need for onsite radiological contingency plans. The basic evaluation measure is the estimated dose to a hypothetical individual located at a selected distance from the release point. The dose for a postulated accident is then compared to dose level above which it has been decided that emergency protective actions and/or emergency planning is warranted. Due to the large number of licenses, the broad variability in the type, quantity, and form of the radionuclides which could be possessed, and the broad range of accidents which could occur, a comprehensive and systematic iterative evaluation process should be used. First, an initial screening analysis, using bounding or conservative assumptions, should be performed; this would eliminate from further consideration the very large fraction of the licenses for which emergency planning is not warranted. Succeeding steps should focus on the relatively small remaining subset of facilities, utilizing more detailed and site-specific information. The final determination as to the need for an emergency response plan should be made on the basis of a realistic and site-specific evaluation for each license. The

overall goal of the entire evaluation process would be to arrive at a balanced and cost-effective determination as to the need, benefits, costs, and potential effectiveness of requiring an emergency response plan.

The basis for performing an evaluation as to the need for emergency planning is contained in guidance from the Commission (USNRC, 1984a). "Emergency planning should be based on realistic assumptions for severe accidents." This contrasts with licensing and design calculations for reactors, which are performed in an intentionally conservative manner. The latter includes dose estimates for routine releases and calculations to insure that safety systems provide a high confidence in meeting 10 CFR Part 100 requirements. The potential hazards from accidents at fuel cycle and by-product material facilities are orders of magnitude smaller than the hazards from reactor accidents; thus emergency response planning for severe accidents at material facilities should also use realistic and best estimate analyses.

This report deals with the initial screening analysis phase of the above evaluation process. Due to the large number of sites and facilities in the initial screening, a number of (arbitrary) assumptions had to be made to insure a margin of assurance that those facilities identified as not exceeding the dose criterion and hence not needing an emergency response plan would indeed be so identified had site-specific information been used. These assumptions are:

1. A severe but not worst-case accident is postulated to have occurred. The probability of occurrence of major accidents is not considered. Hence the source term is a combination of the entire licensed possession limit of all radionuclides and a set of screening release fractions.

2. The estimated dose is for a hypothetical individual located at a relatively close distance from the release point and on the plume centerline. To accommodate variability or uncertainty in weather conditions (except for wind direction, which is assumed to be constant), the peak dose (99th percentile) from a full distribution was used, at the direction of NRC.

3. The estimated dose for each radionuclide is compared to the dose levels from the ranges given in the EPA protective action guides (1 to 5 rem total body, 5 to 25 rem thyroid).

Each of these is meant to be a bound; each may also be conservative, depending on the particulars of the license or

facility under consideration. Taken in combination, they provide a reasonable level of assurance that the initial screening analysis results are conservative; that is, the initial screening analysis identified all licenses that should be further considered, and the use of detailed and site-specific information would not identify any others. Also, the use of these assumptions in the screening process is direct and clear, and hence the effect of varying them is relatively easy to understand.

Beyond this set of conservative or bounding assumptions, the remainder of the analysis provides estimates that are as realistic as possible. This principally involves the models and assumptions used in calculating the dose estimates (atmospheric transport and dispersion, and dosimetry). The succeeding steps in the overall evaluation process would then replace the bounding assumptions with more realistic and site-specific information.

A point should be made concerning the use of the guideline dose levels in the proposed protective action guides. They are dose levels for determining whether emergency protective actions should be implemented given that an accidental release has occurred. They were not intended to be used for establishing a priori the need for emergency response planning and preparedness. There are currently no standards or guidelines for the latter. In that absence, this study uses the dose levels in the protective action guides for the screening, and this choice is expected to provide a margin of conservatism to the screening results. This study did not address the subject of dose levels for establishing the need for planning; and hence the (arbitrary) selection of the PAG level should not be viewed as a justification or endorsement for that purpose.

1.3 Task Description and Technical Approach

The principal goal of this program is to develop and perform an initial screening analysis of the some 9400+ licenses issued directly by the NRC. Secondary goals include development of information and data for use in succeeding stages of the evaluation process for specific licenses and facilities, and development of methods and data for use in the preparation and evaluation of additional emergency response planning and preparedness efforts.

Pursuant to these goals, the principal efforts in this project were divided into the following tasks:

1. Development of a comprehensive library of dose estimates (dose at selected distances, expressed as rem per curie released) for radionuclides appearing in the possession limit data base.

2. Compilation, from the NRC license docket file, of the radionuclide possession limit data for each license for input into a computer data base containing this information.

3. Development and application of a computer program for screening of the radionuclide possession limit data to identify those licenses which might exceed the dose criteria and for which emergency planning and preparedness should be further considered.

4. Development of procedures for estimating the size of potential emergency planning zones for the immediate plume exposure pathways. For long-term ground exposures, a method is presented for estimating the extent of contaminated land areas.

A brief description of each of these efforts follows; more detailed discussions will be found in subsequent chapters.

Chapter 2 of this report summarizes the categories of facilities considered and describes in general the range of accidents that might occur. Release fractions are discussed and a set for use in the screening analysis is presented.

The library of dose estimates for each radionuclide was developed from calculations using a slightly modified version of the CRAC2 computer code (Ritchie et al., 1983a; 1983b). CRAC2 was selected because it calculates distributions of doses over a full range of meteorological conditions and allows flexibility in the description of the atmospheric transport and dispersion. The calculations considered (1) the atmospheric transport and dispersion of a 1 curie release of each radionuclide; (2) the exposure of a hypothetical individual at selected distances from the release point via three exposure pathways: external exposure to the plume (cloudshine), inhalation of material from the plume, and exposure to contaminated ground (groundshine); and (3) the resulting dose equivalent (dose commitment) at each selected distance. Some of the models in CRAC2 were modified to meet the conditions and assumptions appropriate for this study.

In prior work concerning human exposures to radionuclides, dose estimates were usually expressed in terms of whole body and critical organ doses, based on the dosimetry and modeling concepts described in the International Commission on Radiation Protection (ICRP) Publication-2 (ICRP, 1959). Recently, improved methods for dose estimation were published by the ICRP in Publications-26, -28, and -30 (ICRP, 1977; 1978; 1979a; 1979b, 1980). The principal change is the use of the effective dose equivalent, which is based on the stochastic risk for each organ or tissue. Since the screening analysis and subsequent licensee

evaluations are concerned with exposures to single (or a few) radionuclides, dosimetry for these individual radionuclides is relatively more important than in the case of reactor accidents involving a very large number of nuclides. Hence, it was felt that dose conversion factors based on the most recent work in the field should be used. For these reasons, the new ICRP dosimetry concepts and models were implemented as part of this study.

A complete discussion of the atmospheric transport and dispersion models and the assumptions used in the calculations are given in Chapter 3. The dosimetry models are described in Chapter 4 and the results of the dose estimate calculations are given in Chapter 5.

The second task was the development of a data base containing the radionuclide possession limit information for all active NRC licenses. Prior to this project, NRC had compiled only identifying and bookkeeping information for each active license in the docket file into a Master File for use with their Material Licensing System (MLS). With the assistance of a subcontractor, International Energy Associates, Limited, a new data base was developed containing the licensed radionuclide possession limit information as available and specified on each license. Most of the data collection and data base development part of the project was funded under a separate contract from NRC/NMSS. These data were then one part of the input for the screening analysis.

Using the dose estimates developed in task one and the radionuclide possession limit information from task two, a screening analysis was performed, which compared the estimated dose arising from a postulated release of a fraction of the licensed inventory to the dose thresholds in the EPA Protective Action Guides. Included are algorithms for handling group medical licenses, broad licenses, combined sources, etc. Results of the screening analysis are the number of licenses for which the threshold level is exceeded, and a ranking of these by the magnitude by which the level is exceeded. In addition, the number of licenses for which these potential doses are dominated by one sealed source are given. A description of the possession limit data base and the results of the screening analysis are presented in Chapter 6.

Finally, in Chapter 7, methods are described for estimating the size of possible emergency planning zones for plume exposures and the potential extent of contaminated land areas. Dose avoidance and mitigation measures for the various exposure pathways are discussed. A summary of the program results and conclusions is provided in the Executive Summary.

CHAPTER 2

Fuel Cycle and By-Product Material Facilities

Facility descriptions, accident analyses, and environmental assessments have been part of the nuclear safety literature for fuel cycle facilities for a number of years. Since this extensive literature is readily available, summary descriptions of fuel cycle facilities will not be included in this report; only the general categories of facility types and a bibliography are presented.

More recent work has begun to examine by-product material facilities, including facility descriptions, accident phenomenologies, and assessments of potential accidents. The latter category of accident evaluations is the least developed, in terms of published safety analysis reports or other studies for a number of facilities, which estimate the size of potential source terms (curies released to the atmosphere) or release fractions (fraction of the inventory that might be released). A recent report (Sutter, 1984) estimating potential source terms for various by-product material facilities is the first attempt to quantify these accidental releases. Since accident source terms or release fractions for the wide variety of facility types found among the 9400+ licenses are not well defined, the screening results are expressed in a way that easily shows the sensitivity to changes in the release fractions. In all fairness to the licensees affected, the final determination as to the need for further emergency planning and preparedness should be based on site-specific information and conditions.

2.1 Facility Descriptions

The large number and variety of facilities licensed by NRC can be categorized in a general way by the type of license (10 CFR Part 30, 40, or 70) and typical facilities usually licensed under each part. This breakdown is shown in Table 2.1.

The Part 30 licenses cover not only the multitude of facilities and activities using relatively small quantities of radioactive material, but also the large quantities associated with manufacturing, R & D and broad scope licenses.

The physical quantities of materials under Part 40 licenses can be very large, as is typical with any mineral extraction and processing industry. However, the corresponding activity of these materials is not that great, as the specific activities of the radioisotopes involved are quite

Table 2.1

Types of Licensed Facilities and Activities

Part 30 By-product Material
- Sealed Source Possession
  - testing, measurement, calibration
- Sealed Source Manufacturing
- Radiopharmacy
- Radiopharmaceutical Manufacturing
- Radiography
- Administration of Medical Isotopes
  - Groups I - VI
- Waste Warehousing
- Research and Development
  - Academic - Universities
  - Industrial
- Broad Scope Licenses

Part 40 Source Material
- Uranium and Thorium Mills
- UF_6 Conversion Plants
- Manufacturing of Products Containing Significant Quantities of Uranium and Thorium

Part 70 Special Nuclear Material
- Research and Development
  - Reactor Fuel
  - Heat and Power Sources
- Reactor Fuel Manufacturing
- Sealed Source Manufacturing
- Sealed Source Possession
- Scrap Recovery

small. For natural uranium and thorium metals, 1 curie of each would weigh 1.5 and 9 metric tons, respectively.

The Part 70 licenses cover a broad range of facilities involving special nuclear material. That part of the commercial light water reactor fuel cycle dealing with research, development, and manufacture of LWR fuel is one of the principal activities licensed under Part 70. As will be seen later in Chapter 6, the largest number of Part 70 licenses are for sealed sources containing significant amounts of plutonium.

A number of facility descriptions have been written and published. Formal environmental statements are written for the major fuel cycle facilities (mills, etc.). Safety analysis reports are required for the larger facilities with significant quantities of radioactive materials (spent fuel reprocessing plants, mixed oxide fuel fabrication plants, etc.). Battelle Pacific Northwest Laboratories has published summary descriptions of all of the active types of fuel cycle facilities (Schneider, 1982). These include discussions of physical layout and construction, material processes and containment, ventilation systems, safety features, and systems, etc. A similar report covers some of the types of facilities licensed under Part 30 (Sutter, 1984).

Because of the literature describing fuel cycle and by-product material facilities, summary descriptions are not included in this report. Table 2.2 is a list of example references covering a variety of facilities and operations; no attempt was made to prepare an exhaustive compilation.

2.2 Accident Environments

Potential accidents and their initiating events can generally be divided into two classes: natural causes, and all other causes. The former class includes tornadoes, earthquakes, and floods. The latter includes fires, mechanical initiating events, breakages, etc., generally related to or a consequence of the activities of man.

Of the natural events leading to radiological accidents, tornadoes create the largest forces and have the largest potential for destruction. Design basis tornado wind speeds range from 240 to 360 mph for the three tornado intensity regions in the United States (USNRC, 1974). Unless a facility's structures were designed to be tornado resistant, the wind forces could both rupture the containment of any radioactive material and forcefully loft the material into the atmosphere. Given the low probability of the occurrence of tornadoes, and since the atmospheric volume into which the material would be dispersed and diluted would be very large, as compared to releases during stable atmospheric

Table 2.2

Example Facility Descriptions and Evaluations

"Environmental Assessment," Combustion Engineering, Inc., Nuclear Fuel Fabrication Plant, Hamatite, Mo., NUREG, November 1982

"Environmental Impact Appraisal of the Allied Chemical Corporation Nuclear Services Division," Uranium Hexafluoride Conversion Facility, Metropolis, IL, Docket No. 40-3392, USNRC, August 1977.

"Environmental Impact Appraisal of the Babcock & Wilcox Nuclear Materials Division Commercial Nuclear Fuel Fabrication Plant," Borough of Apollo, PA., USNRC, October 1978.

"Environment Impact Appraisal," Exxon Nuclear Company, Nuclear Fuel Fabrication Plant, Richland, WA., Docket No. 70-1257, USNRC, August 1981.

"Environmental Impact Appraisal of the Nuclear Fuel Services, Inc., Erwin Plant," Erwin, TN., USNRC, January 1978

"Environmental Impact Appraisal of the Westinghouse Nuclear Fuel Columbia Site (NFCS) Commercial Nuclear Fuel Fabrication Plant," Columbia, SC., USNRC, April 1977

"Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle," NUREG-0116, USNRC, October 1976

"Environmental Statement Related to the Operation of Highland Uranium Solution Mining Project," Exxon Minerals Co., USA, Docket No. 40-8102, NUREG-0489, USNRC, November 1978

"Environmental Statement Related to the Operation of White Mesa Uranium Project Energy Fuels Nuclear, Inc.," Docket No. 40-8681, NUREG-0556, USNRC, May 1979.

"Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel," Project No. M-4, NUREG-0575, Vol. 2, USNRC, August 1979.

conditions, the likelihood of significant exposure would be negligible. Also, unless the facility hit was a major nuclear installation, the scope and magnitude of other damages would dominate.

Earthquakes generally lack the dispersive forces necessary for a significant airborne release; one would usually expect localized spills and contamination. Floods reaching a licensed facility might cause local contamination; in general, releases would be well diluted. The Uniform Building Code, for example, and local building code requirements would generally provide a modest level of protection against earthquakes, normal wind loads, and floods for facilities of average industrial or commercial construction (UBC, 1979).

In the "other" class, fires and mechanical failures and damage are expected to be the principal causes of radiological accidents. A number of characteristics of the accident environment influence the fraction or quantity of radioactive material that could be released to the atmosphere:

- Pressure
- Temperature, heat
- Duration
- Mechanical damage (leak areas, etc.)
- Air flow (volume, velocity).

Another key factor determining the size of the release is the survivability of mitigation systems when exposed to or stressed by the accident environments.

The properties of the radioactive material and its containment, and how they interact with the accident environments, are a complex problem and directly affect the magnitude and form of the release. Table 2.3 lists many of these factors, along with some examples. The complexity of the interactions between the material in its normal containment and accident environments precludes quantitative definitions of the outcomes of accidents for all facilities under all conditions. Even if "typical" conditions, based on assessments of a few facilities of each type, were to be adopted for the screening analysis, there is no way of knowing how applicable they are to any other of the 9000 licenses or of knowing the level of conservatism of "typical" values.

The principal accident scenario which has been suggested as a basis for evaluating each licensed facility is a major facility fire (Sutter, 1984, McGuire, 1983). In terms of accident environment severity, only a tornado would be

Table 2.3

Factors Influencing the Source Term

Physical and Chemical Form

- Gas--original material, combustion product
- Liquid--salt solution, organic
- Solid--ionic, organic
- Vapor pressure
- Frangability
- Powder--size distribution
  - fraction in aerosol range
- Other--Stable, Reactive, Pyrophoric, etc.
- Influence on radiological health effects
  - Absorptivity (e.g. T_2 vs T_2O)
  - Solubility of aerosol compounds

Containment and Packaging

- Primary--none, sealed source (metal, glass, encapsulated, plated, etc.)
  - Integrity under accident conditions
- Secondary--double packaging
  - Shielding - e.g, massive packaging
  - Work Environment
    - open lab, fume hood, glove box, hot cell

Ventilation System

- Normal--Industrial filters or none
- Radiological Rated
  - Leakage, HEPA Efficiency
  - Adsorption/absorption media (charcoal, zeolite)

Accident Environments

- Driving Force
  - pressure, temperature, mechanical damage
- Duration
- Intensity
- Interaction of adverse environment
  - with relevant material properties:
  - concentration, volatility, dispersability

Survivability of Mitigation Systems

- Design and function
- Distance from accident.

generally expected to have greater damage potential. The probability of a tornado striking any individual facility is expected to be very low, and as discussed previously, the resulting doses would be low due to dilution. The expected chances of fires in general are much higher. The growth of a fire into a major one is strongly dependent on individual facility characteristics (type of construction, operating procedures, fire prevention programs, etc.).

2.3 Release Fractions and Source Terms

The part of any safety or hazards analysis for fuel cycle and by-product material facilities that has the largest degree of uncertainty is definition of the source term (quantity of material that might be released given that an accident occurs). This release quantity is derived from two parts, the fraction of the inventory that could be exposed to accident environments, and the fraction of that susceptible quantity that is estimated to be released to the atmosphere in a dispersible and respirable form (release fraction).

The quantity of a material that is exposed or "at risk," and upon which a facility evaluation should ideally be based, could, for any specific facility, be considerably smaller than the licensed possession limit for that radionuclide (or group of isotopes). This could arise because the amount on hand is less than the licensed possession limit, is distributed among many buildings and locations, etc. Without a detailed investigation of each licensed facility, the possession limit information listed on the license is the only information that is reasonably available for an initial screening. Results of the screening analysis then allow the available resources and effort to be focused on those facilities identified as needing further evaluation. A realistic estimate of the "quantity at risk" is what should be used as part of a final determination of need for additional planning efforts. The Part 40 licenses which allow very large quantities of low activity material are a good example of this; there are probably a number of Part 30 and 70 licenses for which a quantity at risk is much smaller than the limit stated on the license.

For the Part 40 source material licenses with large licensed possession limits, the application of one release fraction to that limit is not reasonable, as the quantity permitted by the license must allow for potentially wide variations in the rates that material is acquired (e.g., mined), processed, packaged, and shipped. For example, a considerable fraction of the licensed amount could be packaged material awaiting shipment. In many cases, a release fraction for storage would be expected to be much smaller than for processing operations. Screening analysis results

would simply identify facilities with large but not necessarily hazardous inventories; the next step would be to identify those for which safety analyses or environmental statements have not already been prepared.

In 1981, a set of release fractions for 55 radionuclides was proposed for use in establishing the need for onsite radiological contingency plans, and was published in an Advance Notice of Proposed Rulemaking in the Federal Register (Fisher, 1981; USNRC, 1981c). The assigned values for release fractions were 0.0 for nondispersible encapsulated materials (sealed sources), 0.001 for stable monolithic solids, 0.01 for other liquids and solids, 0.03 for semivolatile materials, and 1.0 for volatile and/or combustible materials. These release fractions were derived from an evaluation of the common forms of each radionuclide as it would usually be encountered at fuel cycle and by-product material facilities. These nuclides and their release fractions (for nonsealed source forms) are listed in Table 2.4. Henceforth they will be referred to as the Federal Register release fractions.

The uncertainties in establishing or defining release fractions, or even ranges of release fractions, for use in preaccident planning, arise for two reasons: first, from the types of possible accidents that could occur and from these, the selection of those to be used as the basis for emergency planning, and second, from the range of possible release fractions that would be applicable to the selected accidents. The combination of uncertainties does not allow precise, (but not overly conservative) estimates of release fractions to be made for each facility (or category of facilities) for use in an initial screening of all licenses. In performing the screening analysis, it is desired to have the results be a bound; that is, there is reasonable confidence that each facility identified as having passed the screening test (projected offsite dose below a selected level) would indeed pass if verified site-specific information were used.

For the initial screening, a simple set was chosen that is an extension of the Federal Register set. The nuclides are organized into six groups, based on general estimates of potential volatility:

1.	Volatile gases	H3, AR, KR, XE
2.	Volatile, combustible	C, P, S, I
3.	Semivolatile	BR, RU, TE, HG, PO
4.	Inert metals	CO60, TA, W, OS, RE, IR
5.	Neutron source mat'ls	PU238, PU239, AM241
6.	All Others	All other nuclides

Separate release fractions for nonsealed source forms and sealed sources were assigned as follows:

Table 2.4

Federal Register Release Fractions

Nuclide	Release Fraction	Nuclide	Release Fraction
H-3	1.0	Sn-123	0.01
C-14	1.0	Sb-124	0.01
P-32	1.0	I-125	1.0
S-35	1.0	I-129	1.0
Ca-45	0.01	I-131+D	1.0
Sc-46	0.01	Xe-133	1.0
Cr-51	0.01	Cs-134	0.03
Mn-54	0.01	Cs-137+D	0.03
Mn-56	0.01	Ba-140+D	0.01
Fe-55	0.01	Pm-147	0.01
Fe-59	0.01	Tm-170	0.01
Co-60	0.001	Ta-182	0.001
Ni-63	0.01	W-187	0.03
Cu-64	0.01	Ir-192	0.001
Zn-65	0.01	Au-198	0.01
Se-75	1.0	Tl-204	0.01
Kr-85	1.0	Po-210	0.03
Sr-90+D	0.01	Th-228+D	0.01
Zr-93+D	0.01	U-233+D	0.01
Zr-95+D	0.01	Np-237+D	0.01
Nb-95	0.01	Pu-238	0.01
Mo-99+D	0.03	Pu-239	0.01
Tc-99m	0.03	Am-241	0.01*
Ru-103+D	0.03	Am-243	0.01
Ru-105+D	0.03	Cm-242	0.01
Ag-110m+D	0.01	Cm-244	0.01
Cd-113m	0.01	Cf-252	0.01
Sn-113	0.01		

* corrected from 0.001

Taken from (USNRC, 1981c)

Group		Release Fractions Non-SS	SS
1.	H3, AR, KR, XE	1.0	1.0
2.	C, P, S, I	0.5	0.5
3.	BR, RU, TE, HG, PO	0.1	0.01
4.	CO60, TA, W, OS, RE, IR	0.01	0.0001
5.	PU238, PU239, AM241	0.01	0.0005
6.	All other nuclides	0.01	0.001

For the reasons stated above, it should be recognized that these release fractions are assigned parameters in the screening analysis.

Rather than perform only one screening of the possession limit data base with a single set of release fractions, a number of screenings were done to identify the most important types of licenses, groups of nuclides, and material forms (principally sealed sources). In each case, the results are expressed as the number of licenses exceeding the screening criterion. For some, the sensitivity of these members to the selected release fractions is estimated. The overall results of the screenings are intended to provide general (but conservative) estimates of the number of facility licenses which might need to be examined further. The relatively large uncertainties in the individual release fractions do not allow the screening results to be interpreted as a final or exact determination. The numerical values for the release fractions used are discussed and presented in Section 6.3.

In assigning release fractions for screening purposes, care should be taken to keep separate the concepts of (1) probability of a major accident, and (2) the applicable release fraction given that the major accident has occurred. To give credit for a low expected probability by using a lower release fraction could be misleading, with the potential for incomplete or inappropriate response planning. The formal planning and preparations for emergency response could be different for scenarios involving minor accidents and small releases that might occur infrequently or a few times in a facility lifetime, as compared to measures appropriate for large, relatively rare, accidental releases.

As part of an evaluation of a facility which is being considered for additional planning efforts, more detailed information about potential accidents, inventory quantities which might reasonably be expected to be exposed in an accident, and applicable release fractions, can and should be used. Some information is available on airborne release fractions where the form of the material and the dispersive force are relatively well defined. A review report was

recently published by Battelle Pacific Northwest Laboratory on accident-generated particulate materials (Sutter, 1982). Other useful references include fragmentation of liquid drops (Pilch, et al., 1982) and decontamination factors for evaporation or boiling of solutions (Godbee and Kibbey, 1975). The difficult part of a site-specific analysis will be inferring a release fraction for a large accident with many complicating factors and conditions from data or models for comparatively small, localized and idealized phenomenology.

CHAPTER 3

Atmospheric Dispersion and Transport Model

Beginning with the postulated release of each radionuclide, the atmospheric transport and dispersion model estimates the resulting integrated air concentration and level of ground contamination as a function of downwind distance. From these air and ground concentrations, the potential radiation dose to a hypothetical individual can be estimated. The atmospheric transport calculations for this study were performed using a slightly modified version of the CRAC2 (Calculation of Reactor Accident Consequences) computer code (Ritchie, et al., 1983a, 1983b). A new set of dose conversion factors was used for the dosimetry portion of the calculations; this is discussed in Chapter 4. CRAC2 is an improved version of CRAC, the model originally developed as part of the Reactor Safety Study (WASH-1400, USNRC, 1975) for estimating the public health risk from nuclear reactor accidents. CRAC2 was developed at Sandia National Laboratories under an NRC-sponsored research program, and is widely used by utilities and National Laboratories (both in the United States and overseas) and at the NRC. The models and assumptions used in CRAC2 are "best estimates," that is, they are not intentionally conservative; the calculations are performed as best as the data or understanding of the processes involved will allow.

Because of the very large number of licensees and the variety of radionuclides, configurations, possession limits, applications, building types, and so forth, a detailed analysis of the conditions particular to each license is not possible for the initial screening. Consequently, so as to provide guidance that may be applied to the broad range of licenses, a general and simple (i.e., "generic") atmospheric transport and dispersion model has been used. CRAC2 uses the standard Gaussian-plume dispersion model and a simple building-wake effect model. The use of more detailed models is not justified by the nature of the application of these results and by the lack of detailed information needed for such models. Thus, for this initial screening analysis, it is appropriate to use generic assumptions for parameters, such as building size, release duration, etc. The final determination as to the need for additional emergency response planning efforts should be made only on the basis of an analysis which includes the important characteristics and features of each licensed facility.

Some of the more important characteristics of a licensee's site which could impact the potential exposure of an individual and thus the projected dose include:

- Inventory of radionuclides
- Fraction of the inventory released
- Chemical and physical form of the released material
- Duration of the release
- Building size and configuration
- Release height
- Heat content of the plume (i.e., plume buoyancy)
- Possible weather conditions during and following the release
- Distance from the release point.

Complete specifications of each of these parameters for the broad range of hypothetical accidents at all licensed facilities is not possible; the number of calculations required would make the project intractable. Three of the factors, release duration, plume buoyancy, and building size, are treated by assuming values which are reasonably representative of the types of facilities under consideration. The values which have been assumed for all licensees are discussed in Section 3.2. In addition, four factors have been retained as explicit parameters for use in the screening analysis: the individual radionuclides, the quantity released, the distance from the release point, and the weather conditions.

The weather conditions during and following the release are treated as a stochastic variable in CRAC2. Dose estimates are made for a broad range of possible weather conditions, including precipitation, all stability categories, various wind speeds, etc. The frequency of occurrence of each weather condition was determined from 1 year of hourly meteorological observations at a particular site. Weather sequences are sampled from the 1 year of data using an importance-sampling procedure which is more fully described in Section 3.1. The dose estimates, with their associated probabilities, are then used to construct frequency distributions of dose at selected distances. An example of a frequency distribution is given in Figure 3.1, which presents a Complementary Cumulative Distribution Function (CCDF) showing the probability of equaling or exceeding a dose to an individual at a selected distance (n.b., the probability is conditional on the occurrence of the release). From these

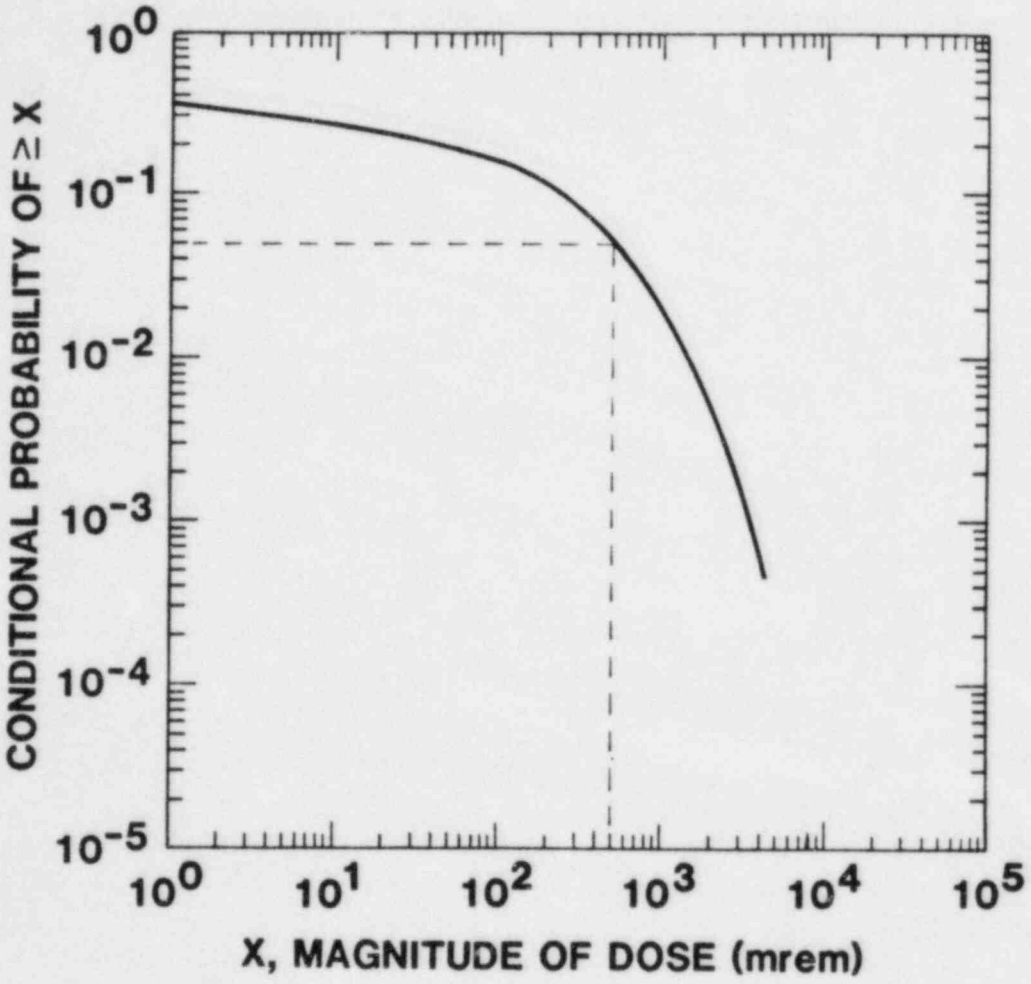

Figure 3.1. An Example of a Complementary Cumulative Distribution Function (CCDF) of Individual Dose at One Selected Distance. In this example, the 95 percentile dose (the dose which would be exceeded 5 percent of the time) is approximately 500 mrem.

distributions, the 95th (for example) percentile doses for each radionuclide, representing the dose level which would be expected to be exceeded 5 percent of the time, can be estimated.

CRAC2 was used in these calculations because it includes a number of useful features for performing this study. For example, factors which can affect the initial plume dimensions and subsequent transport of the material (e.g., building wakes, plume meander, release height, and plume buoyancy) are incorporated in the model and are easily varied. The code contains an extensive radionuclide and dose conversion factor data base, and can construct a frequency distribution of doses at any selected distance. Other features of the code not needed for this analysis, such as estimation of public health and economic consequences, were not used.

CRAC2 has been used in a number of recent risk and safety studies (see for example, Aldrich, et al., 1978; Aldrich and Blond, 1980; Aldrich, et al., 1982) and has recently been compared with similar models used throughout the world (OECD, 1984). The remaining sections of this chapter describe the meteorological sequence sampling method and atmospheric transport and dispersion models used in CRAC2 and the important assumptions and conditions used in the calculations for this analysis.

3.1 Meteorological Sequence Sampling Method

CRAC2 uses a meteorological sequence sampling method to insure that the broad range of possible weather conditions are represented in the calculations. The sampling scheme is designed so that all types of weather conditions, especially those which could result in the highest doses (e.g., precipitation, category F stability, etc.), along with the observed frequencies of these weather conditions, are incorporated in the resulting frequency distributions of dose at selected distances.

The CRAC2 sampling scheme uses 1 year of hourly observations of wind speed, atmospheric stability, and precipitation intensity. The 8760 hours of meteorological data are sorted into 29 categories or "bins." First, each hour is examined to determine if rain occurs anywhere within 50 kilometers (30 miles) of the accident site. If not, a similar examination is made for wind speed slowdowns. If neither of these conditions occurs, the sequence is categorized by the stability and wind speed at the start of a release. A probability for each meteorological bin is estimated from the number of sequences placed in the bin. In the current analysis, four sequences were selected from each bin for use in the calculations. Each selected sequence is used to account for changing weather conditions (i.e.,

hourly changes in wind speed, atmospheric stability, or precipitation intensity) during and following the release. In the present study, the selected distances of interest were generally less than 5 kilometers; thus, in most cases, only the first hour of each sequence was used. Sampling with this method assures that the full range of possible weather conditions, especially low probability, adverse weather conditions, are properly represented. Complete details on the weather sequence sampling scheme may be found in the CRAC2 Model Description (Ritchie, et al., 1983).

The meteorological data used in this study were derived from National Weather Service data from Moline, Illinois. The Moline weather data are fairly typical of data found throughout the United States. A summary of the Moline meteorological data is presented in Table 3.1. For these data, precipitation was observed to occur in 512 hours or 6.0 percent of the time; category F stability with wind speed between 1 and 2 m/sec was observed 8.0 percent of the time. For all the nuclides considered in this study, the 95th percentile and above dose level at 100 m results from weather conditions of category F stability, and a 1 m/sec windspeed. At 1 km, the 95th percentile dose for nuclides which are in the form of particulate matter (i.e., are assumed to dry deposit--see Section 3.2.4), generally result from less stable weather conditions. For noble gases (and tritium), the 95th percentile and above doses always result from category F stability and 1 m/sec wind. Frequency distributions of dose estimates have been found to be relatively insensitive to the source of the meteorological data (Aldrich et al., 1982). This insensitivity is demonstrated in Figure 3.2 which presents 29 CCDFs of dose at a selected distance calculated with 29 different meteorological data files. These files represent the broad range of climatic conditions found in the United States, ranging from arid climates such as Phoenix, Arizona to wet climates such as Apalachicola, Florida. At the 95th percentile, for example, the variation in the predicted dose is less than a factor of three; the value calculated with the Moline data file is approximately in the middle.

The variation in doses between the 29 files becomes substantial only at the very low-probability high-dose end of the distributions (below the 99th percentile). This variation results from differences in the frequency of the most adverse weather conditions.

3.2 Description of the Atmospheric Dispersion Model

CRAC2 calculates integrated air concentrations ($Ci\text{-}sec/m^3$) and levels of ground contamination (Ci/m^2) for each of the selected weather sequences. The transport and dispersion model in CRAC2 is based on a standard Gaussian-plume formulation (Turner, 1970). Assuming the material is

Table 3.1

One Year of Moline, IL Meteorological Data
Summarized Using the Weather Bin Categories

Weather Bin Definitions

R--Rain starting within indicated interval (miles).
S--Slowdown occurring within indicated interval (miles).
A-C D E F--Stability categories.

1(0-1), 2(1-2), 3(2-3), 4(3-5), 5(GT 5)--Wind Speed intervals (m/s).

Weather Bin	Number of Sequences	Percent
1 R (0)	697	5.8
2 R (0-5)	12	0.1
3 R (5-10)	62	0.8
4 R (10-15)	102	1.0
5 R (15-20)	75	0.8
6 R (20-25)	67	0.7
7 R (25-30)	61	0.8
8 S (0-10)	24	0.5
9 S (10-15)	16	0.3
10 S (15-20)	18	0.4
11 S (20-25)	14	0.4
12 S (25-30)	18	0.4
13 C 3	168	3.5
14 C 4	892	10.7
15 D 1	0	0.0
16 D 2	61	1.7
17 D 3	226	4.1
18 D 4	948	10.8
19 D 5	3325	29.4
20 E 1	0	0.0
21 E 2	27	1.0
22 E 3	167	2.6
23 E 4	682	5.7
24 E 5	270	1.5
25 F 1	0	0.0
26 F 2	116	8.2
27 F 3	310	5.3
28 F 4	402	3.5
29 F 5	0	0.00
	8760	100.00

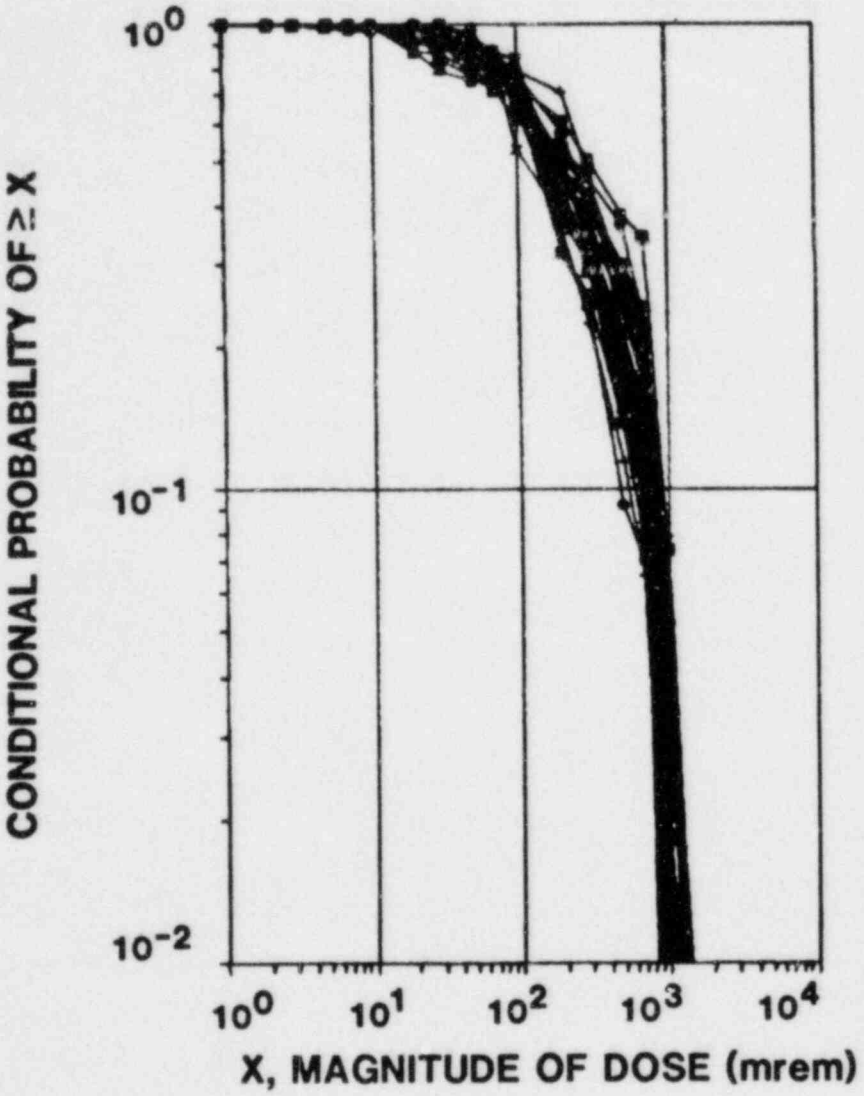

Figure 3.2. Twenty-nine CCDFs of Individual Dose for a Hypothetical Release at a Selected Distance. Each of the twenty-nine CCDFs was calculated with a different meteorological file. The variation in the doses at the 95th percentile is less than a factor of two.

reflected at the ground, the ground-level concentration for a source of strength Q in a uniform wind field is given by:

$$\chi(x,y,0) = \frac{Q}{\pi\sigma_y(x)\sigma_z(x)u} \exp\left(\frac{-y^2}{2\sigma_y^2(x)} + \frac{-h^2}{2\sigma_z^2(x)}\right) \quad (3.1)$$

where $\sigma_y(x)$ and $\sigma_z(x)$, the standard deviations of the crosswind and vertical distributions, respectively, are functions of the downwind distance x and atmospheric stability categories A through F as defined by Pasquill-Gifford (Turner, 1970). u is the mean wind speed and h is the source release height. In the present calculations, ground-level doses on the plume center line (y=0) are considered; thus Equation (3.1) becomes

$$\chi(x,0,0) = \frac{Q}{\pi\sigma_y(x)\sigma_z(x)u} \exp - \left(\frac{h^2}{2\sigma_z^2(x)}\right) . \quad (3.2)$$

Values of $\sigma_y(x)$ and $\sigma_z(x)$ are calculated for each distance interval using the Martin and Tikvart (1968) empirical best-fit functions representing the Pasquill-Gifford curves as provided in Turner (1970). CRAC2 was modified so that the vertical dispersion parameters (σ_z) are appropriate for a surface roughness of 3 cm. CRAC2 was also modified to give the peak of the Gaussian at the plume center line rather than the "top hat" crosswind distribution normally calculated.

The height of the release point is an explicit parameter in the Equation (3.2) for a Gaussian plume. Since the material is assumed to be released into the building wake, at ground level for this work, the release height feature of the model is not used directly. The effect of elevated release (e.g., stacks, buoyant plumes) on estimated doses is discussed in Section 3.2.5).

The dose estimate calculations were performed for distances from the release point ranging from 100 m to 1500 m. Below 100 m the results become increasingly sensitive to modeling assumptions and intervening site features that are difficult to account for in a general calculation. Additionally, if shorter distances were to be considered as the basis for emergency response planning, direct and immediate actions by the facility operator, without offsite assistance, would seem to be the most effective. Results out to 1500 m are provided for use in later site-specific analysis.

For the initial screening analysis, the dose estimates for a distance of 100 m will be used.

Modifications of Equation (3.2) are incorporated in CRAC2 to account for the effects of: (1) radioactive decay, (2) duration of release (plume meander), (3) dry and wet removal processes, (4) building wake, and (5) plume rise caused by sensible heat buoyancy. The implementation of these modifications is described in the following subsections.

3.2.1 Radioactive Decay

CRAC2 accounts for isotope depletion due to radioactive decay using standard formula. Included are decay of nuclides during downwind transport and decay on the ground. Also included is the buildup of any short-lived daughters. Radionuclide decay within the body during the dose commitment period is included implicitly in the dose conversion factor.

A separate correction factor is developed in Section 3.3 to account for radioactive decay within a building prior to release to the atmosphere, for use with those isotopes with short half-lives.

3.2.2 Building Wake Effects

Building wake effects describe the turbulence in the lee of a building. The effect of the turbulence is to increase the initial dilution of the plume, resulting in lower downwind airborne and ground concentrations. Hosker (1982), in a recent review of methods for estimating dispersion in the wake of buildings, has noted the large uncertainties in the models. He suggests that within about 10 building heights, turbulent diffusion is totally dominated by building geometry (e.g., cross-sectional area). For releases into the building wake, i.e., release heights less than the building height, CRAC2 assumes a binormal distribution with initial plume dimensions approximately equal to those of the building (Turner, 1969). For a building of height H and width W, the initial plume standard deviations are set to $\sigma_y = W/3$ and $\sigma_z = H/2.15$. For the initial screening analysis, a generic building size of H = 10 m and W = 25 m has been assumed.

3.2.3 Plume Meander for Extended Duration Releases

The atmospheric dispersion model increases the lateral spread of the plume to account for plume meander during releases of extended duration. The standard Pasquill-Gifford curves are appropriate for a release duration of about 3 minutes. To account for plume meander for releases of longer duration, the horizontal dispersion parameter (σ_y) is increased according to the formula recommended by Gifford (1975). For a release duration of T minutes

$$\sigma_y(T) = \sigma_y(3\ \text{min})\left(\frac{T}{3\text{min}}\right)^B \qquad \begin{matrix} B = 0.2 \text{ for } 3 < T < 60 \text{ min} \\ B = 0.25 \text{ for } 60 < T < 600 \text{ min} \end{matrix} .$$

Releases of duration greater than 600 minutes (10 hours) would be treated as 10-hour releases. Within 10 buildings heights, building wake effects are assumed to dominate; the correction for plume meander is made only beyond 10 building heights.

For the initial screening analysis, a generic release duration of 30 minutes has been assumed. For this release duration, σ_y would be increased by about a factor of 1.6. In CRAC2, the release rate is assumed to be uniform over the full duration of release and the wind direction is assumed to be constant.

3.2.4 Dry and Wet Removal Processes

The CRAC2 atmospheric dispersion model accounts for particulate depletion due to dry and wet removal processes during downwind transport using the source depletion method (Slade, 1968). Dry removal occurs by gravitational settling, turbulent diffusion, and impaction with the ground; these processes are modeled by means of a deposition velocity. Wet removal occurs by scavenging of material during precipitation.

For dry deposition, the level of ground contamination is given by the equation:

$$GC = \chi\, v_d$$

where GC = Ground contamination (Ci/m^2),

χ = Integrated air concentration at ground level ($Ci\text{-}sec/m^3$), and

v_d = Deposition velocity (m/sec).

The dependence on particle size of the deposition rate from a plume is shown in Figure 3.3. For small particles, high diffusion rates lead to contact with and absorption by the ground. Above about 2 microns, gravitational settling dominates.

For wet removal, the fraction f_w of each isotope removed from the plume by precipitation is given in terms of the washout coefficient Λ:

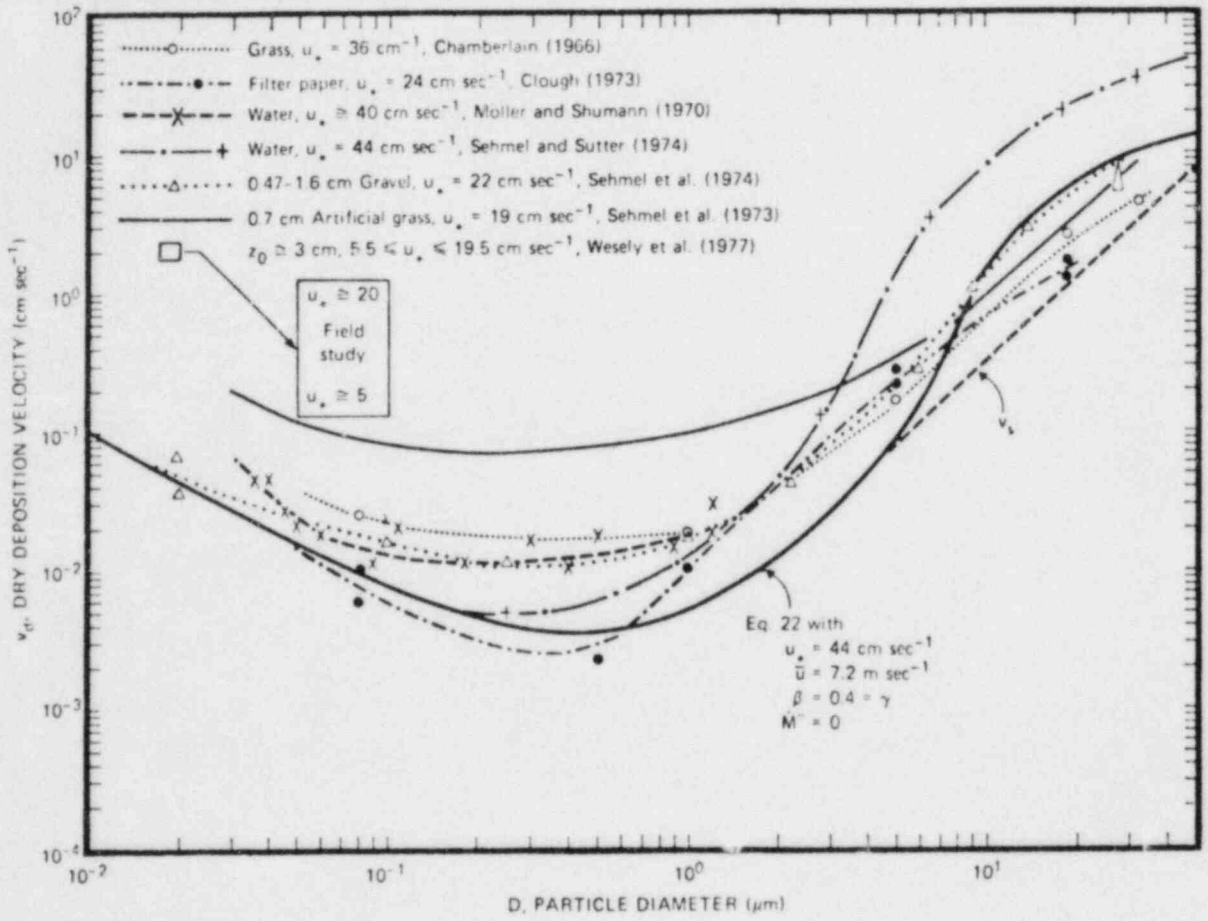

Figure 3.3. Theoretical Predictions and Experimental Determinations of the Dry Deposition Velocity as a Function of Particle Size (Slinn, 1978)

$$f_w = 1 - \exp(-\Lambda t)$$

where t is the duration of precipitation (sec) and Λ is given by:

$$\Lambda = CR \quad .$$

R is the observed rain rate (mm/hr) and C is 10^{-3} (hr/mm sec) for unstable and neutral atmospheric conditions and 10^{-4} for stable atmospheric conditions.

For the calculations, a deposition velocity of 1 cm/sec is assumed for all materials except the noble gases and tritium, for which v_d and Λ are both assumed to be zero; that is, no deposition or depletion occurs. Discussion of the effect of deposition velocity on predicted ground contamination levels is presented in Chapter 7.

3.2.5 Plume Rise

Some accidents could generate a considerable amount of heat, which, if released along with the radionuclides, would result in buoyant plume rise. Inclusion of plume rise would generally decrease the air and ground concentrations, especially at close-in distances.

In CRAC2, all buoyant plumes are subject to plume rise. Buoyant plume rise is calculated using the methods summarized by Briggs (1975). However, due to the large uncertainty in the models used to predict buoyant plume rise as well as in the parameters used in these models (e.g., energy release rate, source location, etc.), no plume buoyancy has been assumed in these initial screening calculations. However, if an initial plume height of 50 meters were to be assumed (resulting from either a 50 m stack or plume buoyancy) and no building wake effects are considered, the inhalation dose at 100 m would generally be about a factor of 10 lower than the values calculated in this study.

3.3 Building Ventilation Correction Factor

For atmospheric releases of radionuclides with relatively short half-lives, as compared to the building ventilation rate, a correction factor has been developed to account for the radioactive decay which occurs within the building prior to release to the atmosphere. This correction factor is in addition to the radioactive decay model within CRAC2, which considers decay only after the material has been released to the atmosphere. Correction for short-lived isotopes would be important for criticality accidents located within a building or other enclosure such that the

time for each air change is on the order of or longer than the half-life. It could also be used for accident scenarios at the types of facilities which manufacture or handle such short-lived isotopes. For criticality releases, the applicable release fractions for the noble gases and radioiodines are specified in Regulatory Guide 3.34 (USNRC, 1979).

Consider the time rate of change of the quantity of material outside, due to exhaust from the building, but not including radioactive decay which occurs outside:

$$\frac{dN_O}{dt} = R\,C_I = \frac{R}{V}\,N_I$$

where N_O is the quantity of material outside, R is the ventilation rate, V is the building or room volume, C_I is the concentration of material inside, and N_I is the quantity of material inside. The amount of material inside decreases with time due to exhaust from the building and due to radioactive decay, and can be expressed as:

$$N_I = N_{Io}\,\exp - \left(\lambda + \frac{R}{V}\right)t$$

where λ is the radioactive decay constant. Combining these equations and integrating gives an expression for the quantity of material that is ultimately released:

$$N_O = N_{Io}\left(1 + \frac{\lambda\,V}{R}\right)^{-1}$$

where N_{Io} is the total amount of the nuclide released to the room or building atmosphere from the accident source. Complete and instantaneous mixing is assumed to occur in the room.

For four short-lived nuclides that are specified for criticality releases (USNRC, 1979), correction factors are given in the following table for three different ventilation rates. The units of R/V are volumes per hour.

Nuclide	$T_{1/2}$	λ	R/V(/hr) =	Correction Factors 2	5	10
KR89	0.05 hr	13.9/hr		0.13	0.26	0.42
XE137	0.06	11.6		0.15	0.30	0.46
XE138	0.24	2.89		0.41	0.63	0.78
I134	0.88	0.79		0.72	0.86	0.93

These building ventilation correction factors would reduce the total dose for the standard criticality release (USNRC, 1979) by a factor of 2 to 3 for a ventilation rate of 5 volumes per hour.

CHAPTER 4

Dosimetry and Implementation of Protective Action Guides (PAG's)

In the assessment of the potential impact of accidental radionuclide releases from fuel cycle or by-product material facilities upon the surrounding public, the CRAC2 computer code performs two types of calculations: (1) the atmospheric transport and dispersion of the radionuclides following an accidental release (described in Chapter 3), and (2) the estimation of dose received following exposure to the released radionuclides (this chapter). Included in CRAC2 are models to estimate the intake of radionuclides via inhalation from the passing plume, external exposure from the passing plume, and external exposure from radionuclides deposited on the ground. The exposures are combined with dose conversion factors to estimate the dose to an individual from the various radionuclides at selected distances from the release point. Portions of CRAC2 dealing with chronic exposures (ingestion, contaminated drinking water, etc.) are not used for this work. The three exposure pathways and related dosimetry are described in Section 4.1.

The dose factor data normally used in CRAC2 was replaced with new dose conversion factors for approximately 200 radionuclides for each of the three exposure pathways. These dose factors incorporate the new and revised modeling approaches presented in International Commission on Radiological Protection (ICRP) Publication-30 (ICRP, 1979a; 1979b; 1980) for internally deposited radionuclides and in NUREG/CR-1918 (Kocher, 1981) for external exposures. The dose conversion factors are discussed in Section 4.2.

In Publication-26, the ICRP recommends use of the effective dose equivalent to replace the total (whole) body and critical organ concepts used in ICRP Publication-2 (ICRP, 1959). The effective dose equivalent (ICRP, 1977) results from weighting the dose equivalent values for the various organs by a factor based on the stochastic risk for the respective organ. The effective dose equivalent is discussed in more detail in Section 4.3.

The proposed Protective Action Guide for radiation exposures (EPA, 1980) are based on the total body and critical organ dosimetric concepts proposed in ICRP Publication-2 (ICRP, 1959). A consistent approach for implementing the new dosimetric concepts, based on the effective dose equivalent, in conjunction with the EPA guidelines, is presented and discussed in Section 4.4.

4.1 Exposure Pathways

Three exposure pathways are considered for airborne releases of radionuclides and are modeled in CRAC2. The inhalation pathway considers exposure from internally deposited radionuclides which are inhaled from the passing plume. A standard breathing rate of 2.66×10^{-4} m^3/sec was assumed. This breathing rate corresponds to the average breathing rate for a Reference Man assuming 16 hours of light activity and 8 hours of rest (ICRP, 1975). The dose conversion factors for inhaled radionuclides are for estimating a 50-year integrated dose equivalent following a 1 curie intake. The term "dose equivalent" in ICRP-30 is similar to the "dose commitment" in ICRP-2.

The external exposure pathways include exposure from the passing plume and exposure to radionuclides deposited on the ground. The external exposure (cloudshine) from the plume assumed no shielding (thus a shielding factor of 1.0) and an exposure time equivalent to the duration of the passing contaminated cloud. Rather than the usual semi-infinite cloud assumption for calculating cloudshine doses, CRAC2 includes a finite cloud correction factor to account for the finite size of the plume (e.g., relatively small under stable atmospheric conditions) and the actual range of gamma rays in air. In the atmospheric transport model, a deposition velocity of 0.01 m/sec was assumed for particulate matter. This deposition velocity corresponds in general to particles in the 1-5 micron range. For ground exposures, a shielding factor of 0.7, accounting for average ground roughness, was assumed and is representative of exposure received 1 meter above ordinary ground. A shielding factor of 1.0 would represent an infinite smooth plane. The dose conversion factors for ground exposures estimate the dose to an individual 1 meter above the ground surface. For this work, an 8-hour ground exposure time was assumed and would account for the lack of an emergency plan and the resulting delay in implementing timely protective actions. For this exposure time, contributions to the dose from ingestion and inhalation of resuspended material would be minimal and have not been considered.

4.2 Dose Conversion Factors

The dose conversion factors for converting the intake of internally deposited radionuclides via inhalation to dose equivalents to the body organs were taken from ICRP Publication-30. The selection of these dose factors is described in Section 4.2.1. Dose conversion factors for external exposures from air submersion and ground deposition are discussed in Section 4.2.2.

4.2.1 Internally Deposited Radionuclides

ICRP Publication-30 presents a set of dose conversion factors for 22 body organs for the inhalation and the ingestion pathways. The calculated dose equivalents are for a unit (curie or becquerel) intake of the radionuclide and represent a 50-year dose equivalent. The dose factors in Publication-30 are expressed as sievert/becquerel inhaled (Sv/Bq) and were converted to rem/curie inhaled (rem/Ci) for use in CRAC2.

The inhalation dose factors in Publication-30 incorporate the Task Group on Lung Dynamics Model (ICRP, 1966) for predicting the movement of particulates within the respiratory tract. In Publication-30, deposition fractions for several particle size distributions (< 1 micron to 10 microns AMAD) are included. Activity Median Aerodynamic Diameter (AMAD) is defined as the diameter of a unit density sphere with the same aerodynamic properties as a particle corresponding to the median activity of the aerosol. For this work, a 1 micron AMAD particle size was assumed for the inhaled radionuclides and the appropriate dose conversion factors are incorporated in the CRAC2 dose factor library.

ICRP Publication-30 considers three clearance classes based on the biological half-life of the radionuclide in the pulmonary region (D = a retention time of days; W = retention time of weeks; Y = retention time of years). The retention of a given radionuclide is determined by the chemical form of the inhaled material. A class D compound is rapidly absorbed from the pulmonary region and distributed to other organs or excreted from the body. The class Y compounds are retained in the lung for long periods and result in increased dose equivalents to the pulmonary tissues.

The ICRP has defined the Annual Limit of Intake (ALI) for each radionuclide and its associated clearance classes. The ALI is a hazard index for protecting the worker in the workplace, and is intended to limit the annual worker exposure to radionuclides. However, the ALI can also be used to rank the radionuclides according to potential hazard to an accidentally exposed individual. In some cases, several clearance classes are defined in Publication-30 for an inhaled radionuclide. Since the chemical form of a radionuclide from a by-product material facility could be a highly uncertain parameter, the clearance class with the lowest ALI (indicating the largest potential dose equivalent) was assigned so as to give a conservative estimate of dose. If the ALI was the same for all clearance classes, then the longest retention class was chosen. For example, if the W and Y classes had the same ALI, the class Y clearance class was selected. These clearance class assignments

and assumptions were used in the CRAC2 calculations of dose estimates (presented in Chapter 5 and Appendix A).

For the uranium and plutonium isotopes, separate dose estimates were made for each of the clearance classes. The dose estimates for these isotopes for the various clearance classes are provided in Chapter 5; the class is indicated by a letter following the isotopic number (e.g., PU239W, PU239Y). At some facilities the chemical form and hence the clearance classes of these isotopes for given processing procedures are well defined. For others and for many accident scenarios, the form and class are unknown and/or uncertain. In the initial screening analysis of all licenses, the retention class giving the highest effective dose equivalent per curie released was used.

4.2.2 External Exposures

The Nuclear Regulatory Commission in a memo from T. E. Murley to H. R. Denton (USNRC, 1980) has recommended the use of NUREG/CR-0494 (Kocher, 1979) in NRC projects for calculating external exposures. A revised set of these dose factors for external exposures was published in NUREG/CR-1918 (Kocher, 1981). These dose factors define dose rates for 23 organs, are based on revised decay data, take into account self-shielding (e.g., bone dose), and are consistent with the ICRP Publication-30 internal dose estimates. As with the internal factors, the units were converted to be consistent with the CRAC2 models.

The dose rate factors presented in NUREG/CR-1918 do not account for the contribution from decay products. For example, the external dose for ^{137}Cs is zero with the entire dose resulting from the gamma emissions of its daughter, ^{137m}Ba, with a 2.6 minute half-life. For this analysis, the dose from daughters with a half-life of less than 4 hours was added to the dose of the parent for estimating the external exposures. Radioactive decay was considered in calculating the 8-hour integrated ground exposure.

4.3 The Effective Dose Equivalent

Guidelines to protect the worker in the workplace were originally published by the ICRP in Publication-2 (ICRP, 1959). These guidelines were based on the dose to the total (whole) body with various critical organs defined for specific radionuclides. Dose conversion factors for estimating the dose commitment to various body organs from the intake of the radionuclides have been developed from these data (Hoenes and Soldat, 1977). Updated radionuclide decay data, revised modeling concepts and the Task Group Lung Model for inhaled particles (ICRP, 1966) were incorporated into the INREM Computer Code to calculate improved dose conversion factors (Killough et al., 1978). The total body concept was

also included in the development of these dose factors. Many regulatory guidelines and risk assessments have been based on these dose conversion factors.

ICRP Publication 26 (ICRP, 1977) recommended the use of the "effective dose equivalent" versus the total body and critical organ concepts that were discussed in previous ICRP documents. The effective dose equivalent is considered more appropriate by the ICRP for assessing risk to a population than the single organ dose and single organ risk estimate concept in ICRP 2. The effective dose equivalent is determined by weighting the dose contribution from various organs by a factor (W_T) which is based on the stochastic risk for each organ or tissue. The Publication 26 dose limitations are based on the principle that the risks should be equal whether the whole body is irradiated uniformly, or whether there is nonuniform irradiation. This condition is met if

$$\sum_T W_T \, H_T \leq H_{WB,L}$$

where W_T is the weighting factor of stochastic risk resulting from exposure of tissue T, H_T is the dose equivalent to tissue T, and $H_{WB,L}$ is the dose equivalent limit for uniform irradiation of the whole body. Publication 26 recommended, when external and internal exposures are received together, that the sum of the external and internal dose values must be less than the imposed limits. It is consistent to add the dose equivalents for individual organs weighted by the fraction W_T for all exposure pathways.

The weighting fractions W_T assigned in Publication 26 are presented in Table 4.1. The gonad category was assigned the higher of the dose equivalents for the ovaries or the testes. The remainder category is composed of the five organs with the highest dose equivalent that are not considered by the other six weighting fractions.

When several exposure pathways (inhalation, external ground, or external cloud) are considered, the five organs having the highest dose equivalents for one pathway may be different from the five organs for another pathway. Hence, the organs in the remainder category could also be different. If the major exposure pathway is used to determine the organs that are included in the remainder category, then the effective dose equivalent values become dependent upon the assumptions of the pathway analysis and the air and ground radionuclide concentrations. In subsequent analyses, the pathway assumptions and radionuclide concentrations could change and would require redefinition of the major exposure pathway and the organs included in the remainder category.

For this work, the organs included in the remainder category for the effective dose equivalent were separately ranked for each pathway to avoid the dependence upon the pathway assumptions and air and ground concentrations. The remainder category for the effective dose equivalent for inhalation may contain a different organ array than for either of the external exposure pathways. As is seen from Table 4.1, the remainder category has a weight of 30 percent and has a significant contribution to the total dose.

For external exposures, ICRP Publication-28 (ICRP, 1978) recommended a weighting factor of 0.01 for the skin. Inclusion of this stochastic risk fraction for skin makes the sum of the weighting factors 1.01 rather than 1.00. Use of the 1.01 weighting sum is consistent with the approach used by Kocher, (1983) in calculating the effective dose equivalent for the external dose conversion factors, and has been used in calculating the effective dose equivalents for external exposure from air and ground contamination. As recommended in ICRP Publication-26 the skin was excluded from the remainder category for the internally deposited radionuclides.

The dose conversion factors for approximately 200 radionuclides and each of the three exposure pathways are presented in Appendix A. The effective dose equivalent is expressed as rem per curie inhaled for the inhalation pathways, as rem/sec per Ci/m^3 for external cloud exposure and as $rem/Ci/m^2$ for an 8-hour integrated exposure to contaminated ground. In addition, the thyroid dose conversion factors for each radionuclide are included in Appendix A, and have the same units as the factors for the effective dose equivalent.

4.4 Implementation of the Effective Dose Equivalent and Protective Action Guides

The dosimetric modeling approaches of ICRP Publications-26 and -30 have replaced the total body concept (from ICRP-2) with the effective dose equivalent. The effective dose equivalent is, however, numerically similar to the dose estimates for the total body. Therefore the total body dose limits from the Protective Action Guides may be used to evaluate estimates of the effective dose equivalent. If a 1 rem limit is imposed upon the effective dose equivalent and a radionuclide is not uniformly distributed in the body organs, high dose commitments to individual organs and tissues could occur. For example, if radioiodine is taken into the body, it is predominately deposited in the thyroid and could result in an extremely high dose to the thyroid. The potential upper dose limits for organs are presented in Table 4.2 for an effective dose equivalent of 1 rem. To obtain the upper dose limits it is necessary for all of the

Table 4.1

Weighting Factor (W_T) for Effective Dose Equivalent

Organ	W_T
Gonads	0.25
Breast	0.15
Red Bone Marrow	0.12
Lung	0.12
Thyroid	0.03
Bone Surface	0.03
Remainder*	0.30
Total	1.00

*W_T of 0.06 for each of the 5 Organs of the remainder category with the highest dose equivalents (includes GI tract)

Taken from ICRP Publication-26 (ICRP, 1977)

Table 4.2

Weighted Dose Equivalent
and
Protective Action Guides
Assuming a 1 rem Limit for the Effective Dose Equivalent

Tissue	W_T	Potential Upper Dose
Gonads	0.25	4 rem
Breast	0.15	7 rem
Red Bone Marrow	0.12	8 rem
Lung	0.12	8 rem
Thyroid	0.03	33 rem
Bone Surface	0.03	33 rem
Remainder	0.30/5 Organs	17 rem Per Organ
Total	1.0	

radionuclide to be deposited exclusively in the respective organ.

ICRP Publication-26 recommended a 5 rem limit to prevent stochastic effects in workers and a 50 rem limit for the prevention of nonstochastic effects. The nonstochastic effects are those observed after a given dose level is achieved (e.g., cataracts). The nonstochastic limit is imposed to constrain any exposure that fulfills the limitation of the stochastic effects. For the general public, ICRP Publication-26 recommended a reduction of 1/10 for the stochastic and nonstochastic limits. These recommendations are for routine releases in a working environment and do not address accidental (nonroutine) releases. For accidental releases exposing the general public, the range of 1 to 5 rem from the Protective Action Guides for limits on the total body dose (and the effective dose equivalent) is within the exposure recommendations of ICRP Publication-26. This approach appears to be a consistent application of the EPA Protective Action Guides and the new dosimetric approaches of ICRP Publications-26 and -30 (Runkle and Johnson, 1983; Eckerman, 1983).

At higher dose levels (e.g., 5 rem EDE), limits must be placed on exposures to specific organs other than the thyroid. In particular, for a few isotopes the kidney is the limiting organ and for many alpha emitters (and a few others) the bone surface dose is limiting. Tables of organ dose estimates for these are provided in Chapter 5. In Chapter 6, screenings at the 5 rem EDE level are modified to include these organ limits.

For thyroid exposures, the limits in the Protective Action Guides are 5 to 25 rem. The principal nuclides are the radioiodines and tellurium that decays to radioiodine. The definition of the thyroid was not modified in ICRP Publication-30, as compared to Publication-2, and therefore the limits in the Protection Action Guides proposed in 1975 (and revised in 1980) are directly applicable.

CHAPTER 5

Dose Calculation Results

Estimates of the expected dose at several selected distances from 100 m to 1500 m were calculated for nearly all of the radionuclides appearing in the possession limit data base. These calculations were performed using a slightly modified version of the CRAC2 computer code; the atmospheric transport and dispersion models were described in Chapter 3 and the dosimetry models were described in Chapter 4. Except for a very few, very uncommon isotopes, the list of approximately 214 radionuclides covers virtually all of the radionuclides in the possession limit data base and for which dose conversion factors are available. In addition, dose estimates are provided for the different solubility classes of two of the more important elements (uranium and plutonium).

By virtue of the structure of the atmospheric transport and dispersion models and the dosimetric models, the estimated dose scales linearly with the source strength (quantity of radioactive material released). Thus only one basic set of calculations need be performed; the results can then be scaled for various applications according to the size of the release. The dose estimates in the following tables are for a unit release of one (1) curie of each radionuclide, and have units of rem per curie released.

In summary, the basic assumptions used in the atmospheric transport and dispersion calculations include a ground-level release, neutrally buoyant Gaussian plume, constant wind direction, and ground-level exposure point. The released material is assumed to be entrained in the wake of the building, which is 25-m wide by 10-m high. Within the constant direction wind field, the plume is assumed to meander, such that the integrated dose is somewhat lower. For the ground exposure pathway, an 8 hour exposure time is assumed, after which the individual is assumed to be removed to an uncontaminated location. These effects are intended to be representative of the conditions that may be encountered at a typical facility. While one single condition or assumption may be nonconservative at an individual facility (in which case the dose estimated here would be too low), the combination of these assumptions are expected to provide realistic or slightly conservative dose estimates.

Variability and uncertainty in local weather conditions can have a large effect on estimated doses and the probabilities of occurrence of such doses. To provide a framework

for bounding the effects of varying meteorology, dose estimates were calculated for a full range of meteorological conditions and a frequency distribution was constructed for each radionuclide and for each distance. From these distributions, dose estimates were selected at the desired level of conservatism; in our case, the 99th percentile, as requested by NRC. For randomly distributed accidents, the actual dose would be expected to be lower 99 percent of the time, with a 1 percent chance of being higher. To use an even higher percentile level would lower the confidence level due to an insufficient number of meteorological samples contributing to the high dose/low probability portion of the frequency distribution.

Using the assumptions and methods described above and in the previous chapters, estimates of the effective dose equivalent at the 99th percentile are presented in Table 5.1 for the full set of radionuclides and for several selected distances from 100 m to 1500 m. For the important uranium and plutonium isotopes, dose estimates are provided for the different clearance classes.

Thyroid dose estimates for the radioiodines and ^{132}Te are listed in Table 5.2. The decay of ^{132}Te (78 hour half-life) to ^{132}I (2.3 hour half-life) is the source of that isotope's thyroid dose. With respect to the exposure limits in the EPA Protective Action Guides, the thyroid dose will be the limiting dose (rather than the effective dose equivalent) for each of the nuclides in Table 5.2 except ^{132}I and ^{134}I, which have relatively small thyroid doses.

As discussed in Section 4.4, the effective dose equivalent is appropriate for protecting the public from exposures that are on the order of 1 rem or less. For significantly higher doses, two other organs become important (kidneys and bone surface) and limits should be placed on these exposures. Table 5.3 lists the kidney dose estimates for the two cadmium nuclides. These should be used with the appropriate limit when the effective dose equivalent exceeds about 5 rem. Similarly, Table 5.4 lists the bone surface dose estimates for those nuclides for which this organ is more sensitive (again above about 5 rem EDE).

In accident scenario evaluations, it is often helpful to know the relative contributions to the total dose from each of the exposure pathways (external cloud, external ground, and inhalation). This information is especially useful in assessing the potential effectiveness of possible emergency response actions. In Table 5.5, these relative contributions are listed for each radionuclide for the effective dose equivalent. These percentages are relatively insensitive to distance for the range of distances considered in Table 5.1. The thyroid dose is essentially dependent only on the inhalation pathway.

Table 5.1

Total Effective Dose Equivalent (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
H3	1.3E-4	6.8E-5	4.3E-5	3.1E-5	2.3E-5	9.5E-6	5.6E-6
C14	1.9E-3	8.9E-4	5.2E-4	3.4E-4	2.4E-4	7.5E-5	3.6E-5
F18	7.7E-4	3.6E-4	2.2E-4	1.4E-4	1.0E-4	3.0E-5	1.3E-5
NA22	1.1E-2	5.4E-3	3.2E-3	2.1E-3	1.5E-3	4.6E-4	2.2E-4
NA24	7.6E-3	3.6E-3	2.1E-3	1.4E-3	1.0E-3	3.1E-4	1.4E-4
MG28	1.0E-2	4.7E-3	2.8E-3	1.8E-3	1.3E-3	4.1E-4	1.9E-4
SI31	2.6E-4	1.2E-4	7.2E-5	4.7E-5	3.3E-5	9.9E-6	4.5E-6
P32	1.4E-2	6.7E-3	3.9E-3	2.5E-3	1.8E-3	5.6E-4	2.7E-4
P33	2.0E-3	9.8E-4	5.7E-4	3.7E-4	2.6E-4	8.3E-5	4.0E-5
S35	2.2E-3	1.0E-3	6.1E-4	4.0E-4	2.8E-4	8.8E-5	4.2E-5
CL36	1.9E-2	9.3E-3	5.4E-3	3.5E-3	2.5E-3	7.8E-4	3.7E-4
AR37	4.4E-11	3.1E-11	2.3E-11	1.9E-11	1.6E-11	9.1E-12	6.4E-12
AR41	3.9E-5	2.7E-5	2.0E-5	1.6E-5	1.3E-5	7.3E-6	4.9E-6
K40	1.1E-2	5.5E-3	3.2E-3	2.1E-3	1.5E-3	4.6E-4	2.2E-4
K42	1.9E-3	9.0E-4	5.3E-4	3.4E-4	2.4E-4	7.6E-5	3.5E-5
CA45	5.8E-3	2.8E-3	1.6E-3	1.1E-3	7.6E-4	2.4E-4	1.1E-4
CA47	7.8E-3	3.7E-3	2.2E-3	1.4E-3	1.0E-3	3.2E-4	1.5E-4
SC46	3.0E-2	1.5E-2	8.4E-3	5.5E-3	3.9E-3	1.2E-3	5.8E-4
SC47	1.9E-3	9.0E-4	5.2E-4	3.4E-4	2.4E-4	7.6E-5	3.6E-5
TI44	9.0E-1	4.3E-1	2.5E-1	1.7E-1	1.2E-1	3.7E-2	1.7E-2
V48	1.5E-2	7.1E-3	4.2E-3	2.7E-3	1.9E-3	6.1E-4	2.8E-4
CR51	3.7E-4	1.8E-4	1.0E-4	6.7E-5	4.8E-5	1.5E-5	7.0E-6
MN54	7.7E-3	3.7E-3	2.2E-3	1.4E-3	1.0E-3	3.1E-4	1.5E-4
MN56	1.8E-3	8.7E-4	5.1E-4	3.3E-4	2.4E-4	7.3E-5	3.3E-5
FE55	2.4E-3	1.1E-3	6.6E-4	4.4E-4	3.1E-4	9.7E-5	4.6E-5
FE59	1.5E-2	7.4E-3	4.3E-3	2.8E-3	2.0E-3	6.3E-4	3.0E-4
CO57	8.3E-3	4.0E-3	2.3E-3	1.5E-3	1.1E-3	3.4E-4	1.6E-4
CO58	1.2E-2	5.6E-3	3.3E-3	2.1E-3	1.5E-3	4.8E-4	2.2E-4
CO60	2.0E-1	9.5E-2	5.5E-2	3.6E-2	2.6E-2	8.0E-3	3.8E-3
NI59	2.4E-3	1.2E-3	6.7E-4	4.4E-4	3.1E-4	9.8E-5	4.7E-5
NI63	5.6E-3	2.7E-3	1.6E-3	1.0E-3	7.3E-4	2.3E-4	1.1E-4
CU64	5.9E-4	2.8E-4	1.6E-4	1.1E-4	7.6E-5	2.4E-5	1.1E-5
CU67	1.4E-3	6.5E-4	3.8E-4	2.5E-4	1.8E-4	5.5E-5	2.6E-5
ZN65	1.9E-2	9.2E-3	5.3E-3	3.5E-3	2.5E-3	7.8E-4	3.7E-4
GA67	8.3E-4	3.9E-4	2.3E-4	1.5E-4	1.1E-4	3.4E-5	1.6E-5
GA70	2.6E-5	1.2E-5	6.6E-6	4.1E-6	2.7E-6	6.8E-7	2.9E-7
GA72	6.3E-3	2.9E-3	1.8E-3	1.1E-3	8.2E-4	2.5E-4	1.2E-4
GE68	4.8E-2	2.3E-2	1.3E-2	8.8E-3	6.2E-3	2.0E-3	9.3E-4
GE77	2.9E-3	1.4E-3	8.1E-4	5.2E-4	3.8E-4	1.2E-4	5.4E-5
AS72	7.3E-3	3.5E-3	2.0E-3	1.3E-3	9.5E-4	3.0E-4	1.4E-4
AS73	3.1E-3	1.5E-3	8.5E-4	5.6E-4	4.0E-4	1.2E-4	5.9E-5
AS74	8.7E-3	4.2E-3	2.4E-3	1.6E-3	1.1E-3	3.5E-4	1.7E-4
AS76	4.4E-3	2.1E-3	1.2E-3	8.0E-4	5.7E-4	1.8E-4	8.3E-5
AS77	9.6E-4	4.6E-4	2.7E-4	1.8E-4	1.2E-4	3.9E-5	1.8E-5
SE75	8.4E-3	4.0E-3	2.3E-3	1.5E-3	1.1E-3	3.4E-4	1.6E-4
SE79	8.7E-3	4.2E-3	2.4E-3	1.6E-3	1.1E-3	3.5E-4	1.7E-4

Table 5.1 (Continued)

Total Effective Dose Equivalent (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
BR76	1.4E-3	6.8E-4	3.9E-4	2.6E-4	1.8E-4	5.6E-5	2.7E-5
BR77	9.2E-4	4.3E-4	2.6E-4	1.7E-4	1.2E-4	3.8E-5	1.7E-5
BR82	6.5E-3	3.1E-3	1.8E-3	1.2E-3	8.5E-4	2.7E-4	1.2E-4
KR83M	3.0E-9	2.0E-9	1.5E-9	1.2E-9	1.0E-9	5.5E-10	3.7E-10
KR85	1.6E-7	1.1E-7	8.2E-8	6.6E-8	5.6E-8	3.2E-8	2.2E-8
KR85M	4.9E-6	3.4E-6	2.6E-6	2.1E-6	1.7E-6	9.7E-7	6.7E-7
KR87	2.7E-5	1.8E-5	1.4E-5	1.1E-5	9.0E-6	4.8E-6	3.1E-6
KR88	8.9E-5	6.1E-5	4.6E-5	3.7E-5	3.1E-5	1.7E-5	1.2E-5
KR89	8.9E-5	4.3E-5	2.3E-5	1.4E-5	9.2E-6	2.6E-6	1.1E-6
RB84	7.7E-3	3.7E-3	2.2E-3	1.4E-3	1.0E-3	3.2E-4	1.5E-4
RB86	6.2E-3	3.0E-3	1.7E-3	1.1E-3	8.1E-4	2.5E-4	1.2E-4
SR85	5.6E-3	2.7E-3	1.6E-3	1.0E-3	7.2E-4	2.3E-4	1.1E-4
SR89	3.7E-2	1.8E-2	1.0E-2	6.7E-3	4.8E-3	1.5E-3	7.1E-4
SR90	1.1E+0	5.5E-1	3.2E-1	2.1E-1	1.5E-1	4.6E-2	2.2E-2
Y90	7.7E-3	3.7E-3	2.1E-3	1.4E-3	9.9E-4	3.1E-4	1.5E-4
Y91	4.3E-2	2.1E-2	1.2E-2	7.9E-3	5.6E-3	1.7E-3	8.3E-4
ZR93	2.8E-1	1.4E-1	7.8E-2	5.2E-2	3.7E-2	1.1E-2	5.5E-3
ZR95	2.2E-2	1.1E-2	6.3E-3	4.1E-3	2.9E-3	9.1E-4	4.3E-4
NB94	3.7E-1	1.8E-1	1.0E-1	6.7E-2	4.8E-2	1.5E-2	7.1E-3
NB95	6.8E-3	3.2E-3	1.9E-3	1.2E-3	8.8E-4	2.8E-4	1.3E-4
MO99	3.9E-3	1.9E-3	1.1E-3	7.1E-4	5.1E-4	1.6E-4	7.5E-5
TC99	7.3E-3	3.5E-3	2.0E-3	1.3E-3	9.5E-4	3.0E-4	1.4E-4
TC99M	2.4E-4	1.1E-4	6.6E-5	4.2E-5	3.1E-5	9.4E-6	4.3E-6
RU103	9.0E-3	4.3E-3	2.5E-3	1.6E-3	1.2E-3	3.6E-4	1.7E-4
RU105	1.5E-3	7.0E-4	4.1E-4	2.7E-4	1.9E-4	5.9E-5	2.7E-5
RU106	4.2E-1	2.0E-1	1.2E-1	7.7E-2	5.5E-2	1.7E-2	8.2E-3
RH106	1.2E-6	3.9E-7	1.6E-7	7.9E-8	4.9E-8	7.6E-9	1.5E-9
PD107	1.1E-2	5.4E-3	3.1E-3	2.1E-3	1.5E-3	4.6E-4	2.2E-4
PD109	1.0E-3	5.0E-4	2.9E-4	1.9E-4	1.3E-4	4.1E-5	2.0E-5
AG110M	7.7E-2	3.7E-2	2.1E-2	1.4E-2	1.0E-2	3.1E-3	1.5E-3
AG111	6.2E-3	3.0E-3	1.7E-3	1.1E-3	8.0E-4	2.5E-4	1.2E-4
CD109	1.0E-1	4.8E-2	2.8E-2	1.8E-2	1.3E-2	4.1E-3	1.9E-3
CD113M	1.3E+0	6.5E-1	3.7E-1	2.5E-1	1.7E-1	5.5E-2	2.6E-2
CD115	4.2E-3	2.0E-3	1.2E-3	7.6E-4	5.4E-4	1.7E-4	8.0E-5
IN111	2.3E-3	1.1E-3	6.4E-4	4.2E-4	3.0E-4	9.3E-5	4.3E-5
IN113M	2.1E-4	9.7E-5	5.7E-5	3.7E-5	2.7E-5	7.9E-6	3.5E-6
IN114M	7.9E-2	3.8E-2	2.2E-2	1.4E-2	1.0E-2	3.2E-3	1.5E-3
SN113	1.0E-2	4.8E-3	2.8E-3	1.8E-3	1.3E-3	4.1E-4	1.9E-4
SN119M	5.5E-3	2.7E-3	1.5E-3	1.0E-3	7.1E-4	2.2E-4	1.1E-4
SN121	4.5E-4	2.2E-4	1.2E-4	8.2E-5	5.8E-5	1.8E-5	8.6E-6
SN121M	1.0E-2	4.9E-3	2.8E-3	1.9E-3	1.3E-3	4.1E-4	2.0E-4
SN123	2.9E-2	1.4E-2	8.0E-3	5.3E-3	3.7E-3	1.2E-3	5.6E-4
SN126	8.1E-2	3.9E-2	2.3E-2	1.5E-2	1.0E-2	3.3E-3	1.6E-3
SB122	5.6E-3	2.7E-3	1.6E-3	1.0E-3	7.3E-4	2.3E-4	1.1E-4
SB124	2.6E-2	1.2E-2	7.2E-3	4.8E-3	3.4E-3	1.1E-3	5.0E-4
SB125	1.2E-2	5.6E-3	3.3E-3	2.1E-3	1.5E-3	4.7E-4	2.3E-4

Table 5.1 (Continued)

Total Effective Dose Equivalent (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
SB126	1.6E-2	7.8E-3	4.6E-3	3.0E-3	2.1E-3	6.7E-4	3.1E-4
SB126M	2.6E-4	1.2E-4	7.0E-5	4.4E-5	3.0E-5	8.1E-6	3.6E-6
TE125M	5.0E-3	2.4E-3	1.4E-3	9.2E-4	6.5E-4	2.0E-4	9.7E-5
TE127	3.0E-4	1.4E-4	8.2E-5	5.4E-5	3.8E-5	1.2E-5	5.6E-6
TE127M	1.9E-2	9.1E-3	5.3E-3	3.5E-3	2.5E-3	7.7E-4	3.7E-4
TE129	1.3E-4	6.2E-5	3.6E-5	2.3E-5	1.6E-5	4.7E-6	2.1E-6
TE129M	2.1E-2	1.0E-2	6.0E-3	3.9E-3	2.8E-3	8.7E-4	4.2E-4
TE132	1.4E-2	6.5E-3	3.8E-3	2.5E-3	1.8E-3	5.6E-4	2.6E-4
I125	2.1E-2	1.0E-2	5.9E-3	3.9E-3	2.8E-3	8.6E-4	4.1E-4
I126	4.0E-2	1.9E-2	1.1E-2	7.3E-3	5.2E-3	1.6E-3	7.7E-4
I129	1.5E-1	7.4E-2	4.3E-2	2.8E-2	2.0E-2	6.2E-3	3.0E-3
I131	3.0E-2	1.4E-2	8.3E-3	5.5E-3	3.9E-3	1.2E-3	5.8E-4
I132	2.3E-3	1.1E-3	6.3E-4	4.0E-4	2.9E-4	8.8E-5	3.9E-5
I133	6.4E-3	3.1E-3	1.8E-3	1.2E-3	8.3E-4	2.6E-4	1.2E-4
I134	1.1E-3	4.9E-4	2.9E-4	1.9E-4	1.3E-4	3.9E-5	1.7E-5
I135	3.9E-3	1.8E-3	1.1E-3	7.1E-4	5.1E-4	1.6E-4	7.1E-5
XE133	1.1E-6	7.3E-7	5.6E-7	4.5E-7	3.8E-7	2.2E-7	1.5E-7
XE133M	9.4E-7	6.5E-7	4.9E-7	4.0E-7	3.4E-7	1.9E-7	1.3E-7
XE135	7.5E-6	5.2E-6	3.9E-6	3.2E-6	2.7E-6	1.5E-6	1.1E-6
XE135M	1.2E-5	7.6E-6	5.4E-6	4.0E-6	3.2E-6	1.2E-6	6.0E-7
XE137	4.8E-6	2.5E-6	1.4E-6	8.5E-7	5.7E-7	1.6E-7	7.4E-8
XE138	1.0E-4	6.6E-5	4.7E-5	3.5E-5	2.7E-5	1.0E-5	4.9E-6
CS134	4.4E-2	2.1E-2	1.2E-2	8.2E-3	5.8E-3	1.8E-3	8.6E-4
CS135	4.0E-3	1.9E-3	1.1E-3	7.4E-4	5.2E-4	1.6E-4	7.8E-5
CS136	1.1E-2	5.3E-3	3.1E-3	2.0E-3	1.4E-3	4.5E-4	2.1E-4
CS137	3.0E-2	1.4E-2	8.3E-3	5.4E-3	3.8E-3	1.2E-3	5.7E-4
BA131	1.6E-3	7.8E-4	4.6E-4	3.0E-4	2.2E-4	6.7E-5	3.1E-5
BA133	7.8E-3	3.7E-3	2.2E-3	1.4E-3	1.0E-3	3.2E-4	1.5E-4
BA137M	1.6E-5	6.0E-6	2.9E-6	1.7E-6	1.2E-6	3.1E-7	1.2E-7
BA140	3.8E-3	1.8E-3	1.0E-3	6.9E-4	4.9E-4	1.5E-4	7.2E-5
LA140	8.7E-3	4.1E-3	2.4E-3	1.6E-3	1.1E-3	3.5E-4	1.6E-4
CE137	3.7E-5	1.8E-5	1.0E-5	6.7E-6	4.7E-6	1.5E-6	6.9E-7
CE139	8.3E-3	4.0E-3	2.3E-3	1.5E-3	1.1E-3	3.4E-4	1.6E-4
CE141	8.1E-3	3.9E-3	2.2E-3	1.5E-3	1.0E-3	3.3E-4	1.6E-4
CE143	3.6E-3	1.7E-3	1.0E-3	6.6E-4	4.7E-4	1.5E-4	6.9E-5
CE144	3.3E-1	1.6E-1	9.2E-2	6.0E-2	4.3E-2	1.3E-2	6.4E-3
PR143	7.2E-3	3.5E-3	2.0E-3	1.3E-3	9.3E-4	2.9E-4	1.4E-4
PR144	5.5E-5	2.5E-5	1.4E-5	8.4E-6	5.6E-6	1.4E-6	5.8E-7
PR144M	8.6E-6	3.6E-6	1.9E-6	1.1E-6	7.0E-7	1.7E-7	7.8E-8
ND147	6.3E-3	3.1E-3	1.8E-3	1.2E-3	8.2E-4	2.6E-4	1.2E-4
PM145	2.2E-2	1.1E-2	6.2E-3	4.1E-3	2.9E-3	9.1E-4	4.3E-4
PM147	2.3E-2	1.1E-2	6.3E-3	4.2E-3	2.9E-3	9.2E-4	4.4E-4
SM145	9.7E-3	4.7E-3	2.7E-3	1.8E-3	1.3E-3	3.9E-4	1.9E-4
SM151	2.6E-2	1.3E-2	7.3E-3	4.8E-3	3.4E-3	1.1E-3	5.1E-4
EU152	2.0E-1	9.5E-2	5.5E-2	3.6E-2	2.6E-2	8.0E-3	3.8E-3
EU154	2.5E-1	1.2E-1	7.1E-2	4.7E-2	3.3E-2	1.0E-2	4.9E-3

Table 5.1 (Continued)

Total Effective Dose Equivalent (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
EU155	3.7E-2	1.8E-2	1.0E-2	6.7E-3	4.8E-3	1.5E-3	7.1E-4
GD151	7.8E-3	3.8E-3	2.2E-3	1.4E-3	1.0E-3	3.2E-4	1.5E-4
GD153	2.1E-2	1.0E-2	5.9E-3	3.9E-3	2.8E-3	8.6E-4	4.1E-4
TB160	2.4E-2	1.2E-2	6.8E-3	4.4E-3	3.2E-3	9.9E-4	4.7E-4
DY159	2.1E-3	1.0E-3	5.9E-4	3.9E-4	2.8E-4	8.7E-5	4.1E-5
DY165	1.8E-4	8.5E-5	4.9E-5	3.2E-5	2.3E-5	6.8E-6	3.1E-6
HO166M	6.9E-1	3.3E-1	1.9E-1	1.3E-1	8.9E-2	2.8E-2	1.3E-2
ER169	1.8E-3	8.8E-4	5.1E-4	3.4E-4	2.4E-4	7.4E-5	3.5E-5
TM170	2.3E-2	1.1E-2	6.5E-3	4.3E-3	3.0E-3	9.4E-4	4.5E-4
YB169	7.8E-3	3.8E-3	2.2E-3	1.4E-3	1.0E-3	3.2E-4	1.5E-4
YB177	1.3E-4	6.0E-5	3.4E-5	2.3E-5	1.6E-5	4.7E-6	2.1E-6
LU172	4.4E-3	2.1E-3	1.2E-3	8.1E-4	5.7E-4	1.8E-4	8.5E-5
LU177	2.2E-3	1.1E-3	6.2E-4	4.1E-4	2.9E-4	9.1E-5	4.3E-5
HF172	2.8E-1	1.4E-1	7.8E-2	5.1E-2	3.6E-2	1.1E-2	5.4E-3
HF181	1.5E-2	7.1E-3	4.1E-3	2.7E-3	1.9E-3	6.0E-4	2.9E-4
TA182	4.2E-2	2.0E-2	1.2E-2	7.7E-3	5.4E-3	1.7E-3	8.1E-4
TA183	4.6E-3	2.2E-3	1.3E-3	8.4E-4	5.9E-4	1.8E-4	8.8E-5
W181	2.3E-4	1.1E-4	6.5E-5	4.3E-5	3.0E-5	9.5E-6	4.4E-6
W185	6.6E-4	3.2E-4	1.8E-4	1.2E-4	8.6E-5	2.7E-5	1.3E-5
W187	1.5E-3	7.2E-4	4.3E-4	2.8E-4	2.0E-4	6.2E-5	2.8E-5
RE188	2.1E-3	9.9E-4	5.7E-4	3.8E-4	2.7E-4	8.3E-5	3.9E-5
OS191	3.8E-3	1.8E-3	1.1E-3	7.0E-4	5.0E-4	1.6E-4	7.4E-5
IR192	2.7E-2	1.3E-2	7.4E-3	4.9E-3	3.5E-3	1.1E-3	5.1E-4
IR194	2.9E-3	1.4E-3	8.1E-4	5.3E-4	3.8E-4	1.2E-4	5.5E-5
PT193	2.0E-4	9.7E-5	5.6E-5	3.7E-5	2.6E-5	8.2E-6	3.9E-6
PT197	5.5E-4	2.7E-4	1.5E-4	1.0E-4	7.2E-5	2.2E-5	1.1E-5
AU198	3.8E-3	1.8E-3	1.1E-3	7.0E-4	5.0E-4	1.5E-4	7.3E-5
AU199	1.5E-3	7.3E-4	4.3E-4	2.8E-4	2.0E-4	6.2E-5	2.9E-5
HG203	7.0E-3	3.4E-3	1.9E-3	1.3E-3	9.1E-4	2.8E-4	1.4E-4
TL201	4.3E-4	2.0E-4	1.2E-4	7.8E-5	5.6E-5	1.7E-5	8.1E-6
TL204	2.2E-3	1.0E-3	6.0E-4	4.0E-4	2.8E-4	8.8E-5	4.2E-5
TL208	1.1E-4	4.3E-5	2.1E-5	1.3E-5	8.5E-6	2.4E-6	9.9E-7
PB210	1.2E+1	5.8E+0	3.3E+0	2.2E+0	1.6E+0	4.9E-1	2.3E-1
BI207	2.1E-2	1.0E-2	5.8E-3	3.8E-3	2.7E-3	8.5E-4	4.0E-4
BI210	1.7E-1	8.3E-2	4.8E-2	3.2E-2	2.2E-2	7.0E-3	3.3E-3
PO210	7.6E+0	3.6E+0	2.1E+0	1.4E+0	9.8E-1	3.1E-1	1.5E-1
RA226	7.5E+0	3.6E+0	2.1E+0	1.4E+0	9.8E-1	3.1E-1	1.5E-1
AC227	5.9E+3	2.8E+3	1.6E+3	1.1E+3	7.6E+2	2.4E+2	1.1E+2
AC228	2.7E-1	1.3E-1	7.5E-2	4.9E-2	3.5E-2	1.1E-2	5.0E-3
TH227	1.4E+1	6.8E+0	4.0E+0	2.6E+0	1.8E+0	5.8E-1	2.8E-1
TH228	2.2E+2	1.1E+2	6.1E+1	4.0E+1	2.9E+1	8.9E+0	4.3E+0
TH230	2.9E+2	1.4E+2	8.0E+1	5.3E+1	3.7E+1	1.2E+1	5.5E+0
TH232	1.4E+3	6.9E+2	4.0E+2	2.6E+2	1.9E+2	5.9E+1	2.8E+1
TH234	3.1E-2	1.5E-2	8.6E-3	5.7E-3	4.0E-3	1.3E-3	6.0E-4
PA231	1.1E+3	5.4E+2	3.1E+2	2.1E+2	1.5E+2	4.6E+1	2.2E+1
PA233	8.9E-3	4.3E-3	2.5E-3	1.6E-3	1.2E-3	3.6E-4	1.7E-4

Table 5.1 (Continued)

Total Effective Dose Equivalent (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
PA234	3.6E-3	1.7E-3	1.0E-3	6.5E-4	4.7E-4	1.4E-4	6.6E-5
U232D	1.1E+1	5.4E+0	3.1E+0	2.0E+0	1.4E+0	4.5E-1	2.2E-1
U232W	1.3E+1	6.3E+0	3.6E+0	2.4E+0	1.7E+0	5.3E-1	2.5E-1
U232Y	5.8E+2	2.8E+2	1.6E+2	1.1E+2	7.5E+1	2.4E+1	1.1E+1
U233D	2.4E+0	1.2E+0	6.8E-1	4.5E-1	3.2E-1	1.0E-1	4.7E-2
U233W	7.0E+0	3.4E+0	2.0E+0	1.3E+0	9.1E-1	2.9E-1	1.4E-1
U233Y	1.2E+2	5.7E+1	3.3E+1	2.2E+1	1.5E+1	4.8E+0	2.3E+0
U234D	2.4E+0	1.2E+0	6.7E-1	4.4E-1	3.1E-1	9.7E-2	4.6E-2
U234W	6.9E+0	3.3E+0	1.9E+0	1.3E+0	9.0E-1	2.8E-1	1.3E-1
U234Y	1.2E+2	5.6E+1	3.2E+1	2.1E+1	1.5E+1	4.7E+0	2.3E+0
U235D	2.2E+0	1.1E+0	6.2E-1	4.1E-1	2.9E-1	9.1E-2	4.3E-2
U235W	6.4E+0	3.1E+0	1.8E+0	1.2E+0	8.3E-1	2.6E-1	1.2E-1
U235Y	1.1E+2	5.2E+1	3.0E+1	2.0E+1	1.4E+1	4.4E+0	2.1E+0
U236D	2.3E+0	1.1E+0	6.3E-1	4.2E-1	3.0E-1	9.3E-2	4.4E-2
U236W	6.5E+0	3.2E+0	1.8E+0	1.2E+0	8.5E-1	2.7E-1	1.3E-1
U236Y	1.1E+2	5.3E+1	3.1E+1	2.0E+1	1.4E+1	4.5E+0	2.1E+0
U238D	2.2E+0	1.0E+0	6.0E-1	4.0E-1	2.8E-1	8.8E-2	4.2E-2
U238W	6.2E+0	3.0E+0	1.7E+0	1.1E+0	8.0E-1	2.5E-1	1.2E-1
U238Y	1.0E+2	5.0E+1	2.9E+1	1.9E+1	1.4E+1	4.2E+0	2.0E+0
NP237	4.4E+2	2.1E+2	1.2E+2	8.1E+1	5.7E+1	1.8E+1	8.5E+0
NP239	2.6E-3	1.2E-3	7.1E-4	4.7E-4	3.3E-4	1.0E-4	4.9E-5
PU236W	1.4E+2	7.0E+1	4.0E+1	2.7E+1	1.9E+1	5.9E+0	2.8E+0
PU236Y	1.2E+2	5.8E+1	3.3E+1	2.2E+1	1.6E+1	4.9E+0	2.3E+0
PU238W	4.1E+2	2.0E+2	1.1E+2	7.5E+1	5.3E+1	1.7E+1	7.9E+0
PU238Y	2.8E+2	1.3E+2	7.7E+1	5.1E+1	3.6E+1	1.1E+1	5.4E+0
PU239W	4.5E+2	2.2E+2	1.3E+2	8.3E+1	5.9E+1	1.8E+1	8.8E+0
PU239Y	3.0E+2	1.4E+2	8.3E+1	5.5E+1	3.9E+1	1.2E+1	5.8E+0
PU240W	4.5E+2	2.2E+2	1.3E+2	8.3E+1	5.9E+1	1.8E+1	8.8E+0
PU240Y	3.0E+2	1.4E+2	8.3E+1	5.5E+1	3.9E+1	1.2E+1	5.8E+0
PU241W	9.1E+0	4.4E+0	2.5E+0	1.7E+0	1.2E+0	3.7E-1	1.8E-1
PU241Y	5.1E+0	2.4E+0	1.4E+0	9.3E-1	6.6E-1	2.1E-1	9.8E-2
PU242W	4.3E+2	2.1E+2	1.2E+2	7.9E+1	5.6E+1	1.8E+1	8.4E+0
PU242Y	2.8E+2	1.4E+2	7.9E+1	5.2E+1	3.7E+1	1.2E+1	5.5E+0
AM241	4.7E+2	2.2E+2	1.3E+2	8.6E+1	6.1E+1	1.9E+1	9.0E+0
AM242	5.3E-2	2.5E-2	1.5E-2	9.6E-3	6.8E-3	2.1E-3	1.0E-3
AM242M	4.5E+2	2.2E+2	1.3E+2	8.3E+1	5.8E+1	1.8E+1	8.7E+0
AM243	4.7E+2	2.2E+2	1.3E+2	8.6E+1	6.0E+1	1.9E+1	9.0E+0
CM242	1.6E+1	7.5E+0	4.3E+0	2.9E+0	2.0E+0	6.3E-1	3.0E-1
CM243	3.1E+2	1.5E+2	8.7E+1	5.7E+1	4.1E+1	1.3E+1	6.1E+0
CM244	2.5E+2	1.2E+2	6.9E+1	4.5E+1	3.2E+1	1.0E+1	4.8E+0
CM245	4.8E+2	2.3E+2	1.3E+2	8.8E+1	6.2E+1	2.0E+1	9.3E+0
CM246	4.8E+2	2.3E+2	1.3E+2	8.8E+1	6.2E+1	1.9E+1	9.3E+0
CM248	1.7E+3	8.4E+2	4.9E+2	3.2E+2	2.3E+2	7.1E+1	3.4E+1
BK247	4.9E+2	2.4E+2	1.4E+2	9.0E+1	6.4E+1	2.0E+1	9.5E+0
BK249	1.2E+0	5.7E-1	3.3E-1	2.2E-1	1.5E-1	4.8E-2	2.3E-2

Table 5.1 (Continued)

Total Effective Dose Equivalent (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
BK250	7.0E-3	3.3E-3	1.9E-3	1.3E-3	8.3E-4	2.7E-4	1.2E-4
CF252	1.1E+2	5.1E+1	3.0E+1	2.0E+1	1.4E+1	4.3E+0	2.1E+0
CF253	2.7E+0	1.3E+0	7.6E-1	5.0E-1	3.5E-1	1.1E-1	5.3E-2

Table 5.2

Thyroid Dose (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
I 125	7.0E-1	3.4E-1	2.0E-1	1.3E-1	9.1E-2	2.9E-2	1.4E-2
I 126	1.3E+0	6.2E-1	3.6E-1	2.4E-1	1.7E-1	5.2E-2	2.5E-2
I 129	5.1E+0	2.4E+0	1.4E+0	9.3E-1	6.6E-1	2.1E-1	9.8E-2
I 131	9.5E-1	4.6E-1	2.6E-1	1.7E-1	1.2E-1	3.9E-2	1.8E-2
I 132	7.7E-3	3.6E-3	2.1E-3	1.4E-3	9.7E-4	2.9E-4	1.3E-4
I 133	1.6E-1	7.7E-2	4.4E-2	2.9E-2	2.1E-2	6.4E-3	3.0E-3
I 134	1.9E-3	9.0E-4	5.2E-4	3.4E-4	2.4E-4	6.8E-5	3.0E-5
I 135	3.0E-2	1.5E-2	8.4E-3	5.5E-3	3.9E-3	1.2E-3	5.6E-4
TE132	2.1E-1	1.0E-1	5.8E-2	3.8E-2	2.7E-2	8.5E-3	4.0E-3

Table 5.3

Kidney Dose (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
CD109	1.3E+0	6.2E-1	3.6E-1	2.4E-1	1.7E-1	5.2E-2	2.5E-2
CD113M	1.8E+1	8.6E+0	4.9E+0	3.3E+0	2.3E+0	7.2E-1	3.4E-1

Table 5.4

Bone Surface Dose (99th percentile) vs Distance
Dose in rem for a 1 Curie Release

Isotope	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
ZR93	7.1E+0	3.4E+0	2.0E+0	1.3E+0	9.2E-1	2.9E-1	1.4E-1
ZR95	3.4E-1	1.6E-1	9.4E-2	6.2E-2	4.4E-2	1.4E-2	6.5E-3
TE125M	1.0E-1	5.0E-2	2.9E-2	1.9E-2	1.4E-2	4.2E-3	2.0E-3
PM145	2.5E-1	1.2E-1	6.9E-2	4.5E-2	3.2E-2	1.0E-2	4.8E-3
PM147	3.3E-1	1.6E-1	9.2E-2	6.1E-2	4.3E-2	1.3E-2	6.4E-3
SM151	4.5E-1	2.2E-1	1.2E-1	8.2E-2	5.8E-2	1.8E-2	8.7E-3
EU155	4.9E-1	2.4E-1	1.4E-1	9.1E-2	6.4E-2	2.0E-2	9.6E-3
GD151	1.2E-1	5.6E-2	3.2E-2	2.1E-2	1.5E-2	4.7E-3	2.3E-3
GD153	3.0E-1	1.4E-1	8.4E-2	5.5E-2	3.9E-2	1.2E-2	5.8E-3
HF172	4.7E+0	2.3E+0	1.3E+0	8.7E-1	6.1E-1	1.9E-1	9.1E-2
HF181	2.6E-1	1.3E-1	7.3E-2	4.8E-2	3.4E-2	1.1E-2	5.1E-3
PB210	1.8E+2	8.6E+1	5.0E+1	3.3E+1	2.3E+1	7.2E+0	3.4E+0
AC227	1.0E+5	5.0E+4	2.9E+4	1.9E+4	1.4E+4	4.2E+3	2.0E+3
AC228	4.6E+0	2.2E+0	1.3E+0	8.4E-1	6.0E-1	1.8E-1	8.6E-2
TH228	4.5E+3	2.1E+3	1.2E+3	8.2E+2	5.8E+2	1.8E+2	8.6E+1
TH230	7.0E+3	3.4E+3	2.0E+3	1.3E+3	9.1E+2	2.9E+2	1.4E+2
TH232	3.6E+4	1.7E+4	1.0E+4	6.6E+3	4.7E+3	1.5E+3	7.0E+2
PA231	2.8E+4	1.4E+4	7.9E+3	5.2E+3	3.7E+3	1.1E+3	5.5E+2
U232D	2.1E+2	1.0E+2	5.8E+1	3.8E+1	2.7E+1	8.5E+0	4.0E+0
U233D	3.6E+1	1.8E+1	1.0E+1	6.7E+0	4.7E+0	1.5E+0	7.1E-1
U234D	3.5E+1	1.7E+1	9.9E+0	6.5E+0	4.6E+0	1.4E+0	6.9E-1
U235D	3.3E+1	1.6E+1	9.1E+0	6.0E+0	4.3E+0	1.3E+0	6.4E-1
U236D	3.4E+1	1.6E+1	9.4E+0	6.2E+0	4.4E+0	1.4E+0	6.6E-1
U238D	3.2E+1	1.5E+1	8.9E+0	5.8E+0	4.1E+0	1.3E+0	6.2E-1
NP237	7.8E+3	3.7E+3	2.2E+3	1.4E+3	1.0E+3	3.2E+2	1.5E+2
PU236W	2.4E+3	1.2E+3	6.8E+2	4.5E+2	3.2E+2	9.9E+1	4.7E+1
PU238W	7.2E+3	3.4E+3	2.0E+3	1.3E+3	9.3E+2	2.9E+2	1.4E+2
PU239W	8.0E+3	3.9E+3	2.2E+3	1.5E+3	1.0E+3	3.3E+2	1.6E+2
PU239Y	3.1E+3	1.5E+3	8.6E+2	5.7E+2	4.0E+2	1.3E+2	6.0E+1
PU240W	8.0E+3	3.9E+3	2.2E+3	1.5E+3	1.0E+3	3.3E+2	1.6E+2
PU240Y	3.1E+3	1.5E+3	8.6E+2	5.7E+2	4.0E+2	1.3E+2	6.0E+1
PU241W	1.7E+2	8.0E+1	4.6E+1	3.0E+1	2.2E+1	6.7E+0	3.2E+0
PU241Y	6.9E+1	3.3E+1	1.9E+1	1.3E+1	8.9E+0	2.8E+0	1.3E+0
PU242W	7.6E+3	3.7E+3	2.1E+3	1.4E+3	9.9E+2	3.1E+2	1.5E+2
AM241	8.2E+3	4.0E+3	2.3E+3	1.5E+3	1.1E+3	3.3E+2	1.6E+2
AM242	5.6E-1	2.7E-1	1.5E-1	1.0E-1	7.2E-2	2.2E-2	1.1E-2
AM242M	8.1E+3	3.9E+3	2.2E+3	1.5E+3	1.0E+3	3.3E+2	1.6E+2
AM243	8.2E+3	4.0E+3	2.3E+3	1.5E+3	1.1E+3	3.3E+2	1.6E+2
CM242	1.6E+2	7.9E+1	4.6E+1	3.0E+1	2.1E+1	6.6E+0	3.2E+0
CM243	5.4E+3	2.6E+3	1.5E+3	1.0E+3	7.0E+2	2.2E+2	1.1E+2
CM244	4.3E+3	2.1E+3	1.2E+3	7.8E+2	5.5E+2	1.7E+2	8.3E+1
CM245	8.5E+3	4.1E+3	2.4E+3	1.6E+3	1.1E+3	3.5E+2	1.7E+2
CM246	8.5E+3	4.1E+3	2.4E+3	1.6E+3	1.1E+3	3.4E+2	1.6E+2
CM248	3.1E+4	1.5E+4	8.6E+3	5.7E+3	4.0E+3	1.3E+3	6.0E+2
BK247	8.7E+3	4.2E+3	2.4E+3	1.6E+3	1.1E+3	3.5E+2	1.7E+2
BK249	2.1E+1	1.0E+1	5.9E+0	3.9E+0	2.8E+0	8.6E-1	4.1E-1
BK250	1.0E-1	5.0E-2	2.9E-2	1.9E-2	1.3E-2	4.0E-3	1.8E-3
CF252	1.6E+3	7.6E+2	4.4E+2	2.9E+2	2.1E+2	6.4E+1	3.1E+1

Table 5.5

Pathway Contributions (as percent)
to the Total Effective Dose Equivalent
(C=Cloud, G=Ground, I=Inhalation)

Nuclide	C	G	I	Nuclide	C	G	I
H 3	0	0	100	SE 75	0	11	89
C 14	0	0	100	SE 79	0	0	100
F 18	3	87	9	BR 76	0	0	100
NA 22	1	39	60	BR 77	1	73	26
NA 24	2	84	14	BR 82	1	78	21
MG 28	1	56	43	KR 83M	100	0	0
SI 31	0	27	73	KR 85	100	0	0
P 32	0	1	99	KR 85M	100	0	0
P 33	0	0	100	KR 87	100	0	0
S 35	0	0	100	KR 88	100	0	0
CL 36	0	0	100	KR 89	100	0	0
AR 37	100	0	0	RB 84	0	25	74
AR 41	100	0	0	RB 86	0	6	94
K 40	0	4	96	SR 85	0	20	80
K 42	0	36	63	SR 89	0	0	100
CA 45	0	0	100	SR 90	0	0	100
CA 47	0	26	73	Y 90	0	3	97
SC 46	0	14	86	Y 91	0	0	100
SC 47	0	14	86	ZR 93	0	0	100
TI 44	0	1	99	ZR 95	0	7	93
V 48	1	39	60	NB 94	0	1	99
CR 51	0	20	80	NB 95	0	24	75
MN 54	0	23	77	MO 99	0	10	89
MN 56	3	80	18	TC 99	0	0	100
FE 55	0	0	100	TC 99M	1	86	12
FE 59	0	15	85	RU103	0	12	88
CO 57	0	4	96	RU105	1	72	27
CO 58	0	18	82	RU106	0	0	100
CO 60	0	2	98	RH106	84	16	0
NI 59	0	0	100	PD107	0	0	100
NI 63	0	0	100	PD109	0	7	93
CU 64	1	58	42	AG110M	0	7	92
CU 67	0	20	79	AG111	0	13	87
ZN 65	0	6	94	CD109	0	0	100
GA 67	0	40	59	CD113M	0	0	100
GA 70	0	0	100	CD115	0	11	89
GA 72	1	73	26	IN111	1	67	32
GE 68	0	5	95	IN113M	3	80	17
GE 77	1	67	32	IN114M	0	1	99
AS 72	1	50	49	SN113	0	6	94
AS 73	0	1	99	SN119M	0	0	100
AS 74	0	20	80	SN121	0	0	100
AS 76	0	24	75	SN121M	0	0	100
AS 77	0	3	97	SN123	0	1	99

Table 5.5 (Continued)

Pathway Contributions (as percent)
to the Total Effective Dose Equivalent
(C=Cloud, G=Ground, I=Inhalation)

Nuclide	C	G	I	Nuclide	C	G	I
SN126	0	5	95	PM145	0	0	100
SB122	0	19	81	PM147	0	0	100
SB124	0	15	85	SM145	0	0	100
SB125	0	8	92	SM151	0	0	100
SB126	0	36	63	EU152	0	1	99
SB126M	15	74	11	EU154	0	1	99
TE125M	0	1	99	EU155	0	0	100
TE127	0	6	94	GD151	0	0	100
TE127M	0	0	100	GD153	0	1	99
TE129	1	40	59	TB160	0	9	91
TE129M	0	2	98	DY159	0	0	100
TE132	0	39	61	DY165	0	35	65
I 125	0	0	100	HO166M	0	1	99
I 126	0	3	97	ER169	0	0	100
I 129	0	0	100	TM170	0	0	100
I 131	0	3	97	YB169	0	10	90
I 132	3	83	15	YB177	0	0	100
I 133	0	19	81	LU172	0	0	100
I 134	7	83	11	LU177	0	4	96
I 135	1	71	28	HF172	0	0	100
XE133	100	0	0	HF181	0	8	92
XE133M	100	0	0	TA182	0	6	94
XE135	100	0	0	TA183	0	0	100
XE135M	100	0	0	W 181	0	43	57
XE137	100	0	0	W 185	0	0	100
XE138	100	0	0	W 187	1	63	36
CS134	0	8	92	RE188	0	14	86
CS135	0	0	100	OS191	0	5	95
CS136	1	41	59	IR192	0	7	93
CS137	0	4	95	IR194	0	13	87
BA131	1	63	36	PT193	0	1	99
BA133	0	11	88	PT197	0	10	90
BA137M	61	39	0	AU198	0	24	76
BA140	0	12	88	AU199	0	14	86
LA140	1	50	49	HG203	0	8	92
CE137	0	0	100	TL201	1	51	48
CE139	0	4	95	TL204	0	1	99
CE141	0	2	98	TL208	63	37	0
CE143	0	18	82	PB210	0	0	100
CE144	0	0	100	BI207	0	16	84
PR143	0	1	99	BI210	0	0	100
PR144	2	33	65	PO210	0	0	100
PR144M	15	85	0	RA226	0	0	100
ND147	0	5	95	AC227	0	0	100

Table 5.5 (Continued)

Pathway Contributions (as percent)
to the Total Effective Dose Equivalent
(C=Cloud, G=Ground, I=Inhalation)

Nuclide	C	G	I	Nuclide	C	G	I
AC228	0	0	100	AM243	0	0	100
TH227	0	0	100	CM242	0	0	100
TH228	0	0	100	CM243	0	0	100
TH230	0	0	100	CM244	0	0	100
TH232	0	0	100	CM245	0	0	100
TH234	0	1	99	CM246	0	0	100
PA231	0	0	100	CM248	0	0	100
PA233	0	6	94	BK247	0	0	100
PA234	1	79	20	BK249	0	0	100
U 232D	0	0	100	BK250	0	13	87
U 232W	0	0	100	CF252	0	0	100
U 232Y	0	0	100	CF253	0	0	100
U 233D	0	0	100				
U 233W	0	0	100				
U 233Y	0	0	100				
U 234D	0	0	100				
U 234W	0	0	100				
U 234Y	0	0	100				
U 235D	0	0	100				
U 235W	0	0	100				
U 235Y	0	0	100				
U 236D	0	0	100				
U 236W	0	0	100				
U 236Y	0	0	100				
U 238D	0	0	100				
U 238W	0	0	100				
U 238Y	0	0	100				
NP237	0	0	100				
NP239	0	15	85				
PU236W	0	0	100				
PU236Y	0	0	100				
PU238W	0	0	100				
PU238Y	0	0	100				
PU239W	0	0	100				
PU239Y	0	0	100				
PU240W	0	0	100				
PU240Y	0	0	100				
PU241W	0	0	100				
PU241Y	0	0	100				
PU242W	0	0	100				
PU242Y	0	0	100				
AM241	0	0	100				
AM242	0	0	100				
AM242M	0	0	100				

For facilities in the front end of the fuel cycle, a number of uranium releases are considered. These involve different enrichments of the three naturally occurring isotopes, and compounds with different solubility (clearance) classes. In addition, many of the release scenarios are specified in terms of mass (kg) of material released, rather than a complete specification of the number of curies of each isotope. To make the later analyses somewhat simpler, a table of dose estimates was constructed for four compositions (depleted, natural, LWR enriched, and high enriched) and three clearance classes (D, clearance time of days; W, weeks; and Y, years). These estimates are summarized in Table 5.6; the results are expressed in terms of rem per kg of uranium released.

For many accident scenarios, the chemical toxicity of the material is of concern. For these evaluations, it is useful to know the fraction of the released material that is inhaled. For example, for accidental UF_6 releases the quantity of uranium inhaled is needed to evaluate the potential hazard of heavy metal poisoning. These fractions are tabulated below and have units of (Ci inhaled/Ci released) or (g inhaled/g released):

INTERCEPT FRACTIONS

Distance	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
With Deposition	8.9E-7	4.3E-7	2.5E-7	1.6E-7	1.2E-7	3.6E-8	1.7E-8
Without Deposition	1.0E-6	5.5E-7	3.5E-7	2.5E-7	1.9E-7	7.7E-8	4.5E-8

The intercept fractions with deposition are for use with particulate material. Those without would be for use with tritium. In the case of UF_6 releases, in which HF is formed as the UF_6 is mixed and reacts with moisture in the atmosphere, appropriate values would be in between these two cases. A separate correction factor would have to be supplied if some of the inhaled particulate material were immediately exhaled from the lungs.

For other chemicals, the air concentration at the exposure point is the relevant parameter for evaluating chemical toxicity. In particular, this applies to HF, hydrofluoric acid, which is generated from the hydrolysis of UF_6. The concentration in air (C, g/m^3) can be estimated from the material release rate (MR, g/s) and the amount of atmospheric dilution, given by CHI/Q (s/m^3), as follows:

Table 5.6

Uranium Release Dose Estimates

Composition

Type	% 234U	% 235U	% 238U
Depleted	-	0.2	99.8
Natural	0.005	0.72	99.275
LWR enriched	0.03	3.2	96.77
High enriched	1.1	93.0	5.9

Specific activity

234U	6.27	Ci/kg
235U	2.17E-3	
238U	3.37E-4	

Dose Conversion Factors (rem/Ci released) Distance = 100 m

Nuclide	Class D	Class W	Class Y
234U	2.4	6.9	1.2E2
235U	2.2	6.4	1.1E2
238U	2.2	6.2	1.0E2

Dose Estimates (rem/kg U released) Distance = 100 m

Type	Class D	Class W	Class Y
Depleted	7.5E-4	2.1E-3	3.4E-2
Natural	1.5E-3	4.3E-3	7.3E-2
LWR enriched	5.4E-3	1.5E-2	2.7E-1
High enriched	1.7E-1	4.9E-1	8.5E-0

Dose Conversion Factors (rem/Ci released) Distance = 200 m

Nuclide	Class D	Class W	Class Y
234U	1.2	3.3	5.6E1
235U	1.1	3.1	5.2E1
238U	1.0	3.0	5.0E1

Dose Estimates (rem/kg U released) Distance = 200 m

Type	Class D	Class W	Class Y
Depleted	3.4E-4	1.0E-3	1.7E-2
Natural	7.3E-4	2.1E-3	3.5E-2
LWR enriched	2.7E-3	7.4E-3	1.3E-1
High enriched	8.5E-2	2.4E-1	4.0E-0

Table 5.6 (Continued)

Uranium Release Dose Estimates

Dose Conversion Factors (rem/Ci released) Distance = 300 m

Nuclide	Class D	Class W	Class Y
234U	0.67	1.9	3.2E1
235U	0.62	1.8	3.0E1
238U	0.60	1.7	2.9E1

Dose Estimates (rem/kg U released) Distance = 300 m

Type	Class D	Class W	Class Y
Depleted	2.0E-4	5.8E-4	9.9E-3
Natural	4.2E-4	1.2E-3	2.0E-2
LWR enriched	1.5E-3	4.3E-3	7.2E-2
High enriched	4.7E-2	1.3E-1	2.3E-0

Dose Conversion Factors (rem/Ci released) Distance = 400 m

Nuclide	Class D	Class W	Class Y
234U	0.44	1.3	2.1E1
235U	0.41	1.2	2.0E1
238U	0.40	1.1	1.9E1

Dose Estimates (rem/kg U released) Distance = 400 m

Type	Class D	Class W	Class Y
Depleted	1.4E-4	3.8E-4	6.5E-3
Natural	2.8E-4	7.9E-4	1.3E-2
LWR enriched	9.9E-4	2.9E-3	4.7E-2
High enriched	3.1E-2	9.2E-2	1.5E-0

Dose Conversion Factors (rem/Ci released) Distance = 500 m

Nuclide	Class D	Class W	Class Y
234U	0.31	0.90	1.5E1
235U	0.29	0.83	1.4E1
238U	0.28	0.80	1.4E1

Table 5.6 (Continued)

Uranium Release Dose Estimates

Dose Estimates (rem/kg U released) Distance = 500 m

Type	Class D	Class W	Class Y
Depleted	9.5E-5	2.7E-4	4.8E-3
Natural	2.0E-4	5.6E-4	9.6E-3
LWR enriched	6.9E-4	2.0E-3	3.4E-2
High enriched	2.2E-2	6.4E-2	1.1E-0

Dose Conversion Factors (rem/Ci released) Distance = 1000 m

Nuclide	Class D	Class W	Class Y
234U	9.7E-2	2.8E-1	4.7E+0
235U	9.1E-2	2.6E-1	4.4E+0
238U	8.8E-2	2.5E-1	4.2E+0

Dose Estimates (rem/kg U released) Distance = 1000 m

Type	Class D	Class W	Class Y
Depleted	3.0E-5	8.5E-5	1.4E-3
Natural	6.1E-5	1.8E-4	2.9E-3
LWR enriched	2.2E-4	6.3E-4	1.1E-2
High enriched	6.9E-3	2.0E-2	3.3E-1

Dose Conversion Factors (rem/Ci released) Distance = 1500 m

Nuclide	Class D	Class W	Class Y
234U	4.6E-2	1.3E-1	2.3E+0
235U	4.3E-2	1.2E-1	2.1E+0
238U	4.2E-2	1.2E-1	2.0E+0

Dose Estimates (rem/kg U released) Distance = 1500 m

Type	Class D	Class W	Class Y
Depleted	1.4E-5	4.1E-5	6.8E-4
Natural	2.9E-5	8.3E-5	1.4E-3
LWR enriched	1.0E-4	2.9E-4	5.1E-3
High enriched	3.3E-3	9.2E-3	1.6E-1C

$$C = MR \times (CHI/Q) \quad .$$

The values for CHI/Q are summarized below for the various distances:

CHI/Q VALUES

Distance	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
With Deposition	3.4E-3	1.5E-3	9.4E-4	6.1E-4	4.3E-4	1.4E-4	6.5E-5
Without Deposition	3.9E-3	2.1E-3	1.3E-3	9.3E-4	7.1E-4	2.9E-4	1.7E-4

These were obtained from the intercept fractions above by dividing out the breathing rate of 2.66E-4 m^3/s.

The hydrolysis of UF_6 by moisture in the atmosphere proceeds according to the reaction:

$$UF_6 + 2\ H_2O = UO_2F_2 + 4\ HF \quad .$$

If the starting quantity of UF_6 is 1.48 kg, which contains 1.0 kg of uranium, then 0.34 kg of HF is produced.

The results presented in this chapter are based on the 99th percentile of the distribution for a full range of meteorological conditions. This corresponds, for the meteorological file used, to the f stability, 1 m/s wind-speed weather sequence. As will be seen in Chapter 6 in the screening results, doses based on the licensed possession limit are several orders of magnitude over the selected dose limit for a number of facilities. For these larger licenses, accidents which occurred during average weather conditions would still lead to relatively large estimated doses even at the longer distances. Under these conditions, the wind- speed is higher, on the order of 5 m/s or greater, versus the 1 m/s used above. The implications for emergency response is that up to an order of magnitude less time could be available for the initiation and implementation of dose avoidance measures (e.g., sheltering). For reference, the median dose (50th percentile) from the distribution is smaller by the following factors for a particulate form, inhalation dominated nuclide (eg, PU238Y, PU239Y, etc):

DOSE REDUCTION FACTOR (50th/99th)

Distance	100.M	200.M	300.M	400.M	500.M	1000.M	1500.M
Dose Ratio	0.14	0.11	0.11	0.10	0.10	0.11	0.12

It should also be noted that stable atmospheric conditions generally occur at night, with neutral and unstable conditions generally during the daytime. Thus time of day can lead to shifts in the estimated dose by about an order of magnitude.

CHAPTER 6

Data Base and Screening Results

NRC has had for a number of years a Material Licensing System, part of which is a computer file (called the master file) of license information covering license and docket numbers, identity and address of the licensee, type of license, dates, and other bookkeeping information. The other part is a system to help track the paperwork associated with various licensing actions (applications, renewals, amendments, etc.). One of the first parts of this study was to collect, for use in a computer data base, the radionuclide possession limit information that is specified as part of each license issued by NRC.

It is planned that this possession limit data base will be combined with the (previous) master file into a new License Management System at NRC. For this study, the possession limit data will be used in an initial screening of all licenses to identify those with sufficiently large inventories that accidents releasing radioactive material could lead to excessive radiological exposures. These licensees should then be further evaluated on a site-specific basis as to the need for and potential effectiveness of additional emergency planning and preparedness.

6.1 Data Base Description

The possession limit data base has been developed over the last 2 years with the assistance of a subcontractor, International Energy Associates, Limited, of Washington, D.C. This development effort was part of a separate program funded by NMSS. Based on examination of a sample of the licenses in the docket file, the formats, and methods for the data collection were developed. A key part of this was assembling a dictionary of acronyms, abbreviations, definitions, and rules to be used in copying all the information from the licenses to the computer input forms.

The basic entry in each license for each nuclide or group of nuclides consists of three parts: material type, configuration, and quantity (possession limit). The nomenclature for material type includes single isotopes (H3, CO60, CS137, PU239, etc.), combined sources (CS-AM), medical group licenses (Group 1 through Group 6), broad scope licenses (A-Any, A3-Atomic Numbers 3-83, AXI-Any except iodine, etc.), and others. The configuration is used to describe the physical form or containment of the material; for example: A-any, SS-sealed source, ENC-encapsulated, SOL-solid,

GEN-generator, etc. The quantity could be in terms of activity or mass. For some, a range is allowed. For some sealed sources, the maximum quantity per source and an aggregate limit are specified. For other sealed sources, the maximum quantity per source is given, but not a total, meaning that there is no limit on the total number of sealed sources (e.g., noted as S-1 mCi/0). This quantity notation will be referred to simply as "/0."

A considerable amount of quality assurance work was performed to assure that the computer data base reflected accurately the information on the licenses. A sample of the input forms were checked against the license and similarly against the data base. The configuration abbreviations were checked for conformity with the dictionary. The quantity expression has to meet certain rules; for example, left element of a dual specification smaller than the right. The isotope names were checked for reasonableness (e.g., the mass number corresponds to known isotopes of the element). At this point, there is a reasonable confidence that the data base accurately reflects the license information in the docket file.

The data base used in the screening analysis in this study represents a snapshot of the docket file as of about May 1984. Changes, additions, deletions, etc., to this file are being processed and accumulated as part of a separate NRC program; there are about 200-300 licensing actions processed each month. Eventually, the possession limit data base will be brought up to date and integrated into the on-line, real-time Licensing Management System.

The number of licenses and records in the data base can be summarized as follows:

License Type	Number of Licenses	Number of Material Type Entries
Part 30	8290	30019
Part 40	252	361
Part 70	443	945
Part 00	460	1249
Totals	9445	32574

Part 00 is the collection of licenses for which docket numbers were not available. Licenses issued by agreement states are not included.

Using the data base sort routines, several simple analyses were done on the frequency of occurrence of names in the data base. For the 32574 entries of material types, 608 distinct names were used. The following table shows this by type of license. For each type, selection of a relative few

of these names shows that a large fraction of the total entries can be covered.

Material Type Names

License Type	Total in File Names	Entries	Names* Selected	Number of Entries Covered	Percent Coverage
Part 30	524	30019	96	29329	97
Part 40	20	361	5	338	93
Part 70	129	945	10	731	77
Part 00	114	1249	25	1031	82
Totals		32574		31429	

*10 or more occurrences

For all types of licenses combined, the most commonly occurring names are listed in Table 6.1. Of the 609 material type names in the file, 336 occur 5 or fewer times, with 222 occurring only once.

Similarly, frequency distributions of configuration names show that a relatively small fraction of the complete set of names encompasses almost all of the file. The following table shows this information by license type:

Configuration Names

License Type	Total in File Names	Entries	Names* Selected	Number of Entries Covered	Percent Coverage
Part 30	253	29994	59	29487	98
Part 40	100	361	5	160	44
Part 70	104	945	10	746	79
Part 00	60	1249	9	1111	89
Totals		32549		31516	

*10 or more occurrences

For all types of licenses combined, Table 6.2 lists the most common 45 names (20 or more occurrences). Of the 388 configuration names in the data base, 274 occur 5 or fewer times, with 155 of these occurring only once.

Considerable simplification of the data base could be achieved by sharply reducing the size of the allowed dictionaries. It would also help to eliminate or change duplicative or confusing names (ENF-encapsulated foils, FPS-Foils, plated sources or sealed sources, FSS-foils or sealed sources, SPO-sealed, plated or solid sources, SPS-sealed or plated sources, SS-sealed source; AEC-activated electronic component, IEL-irradiated electronic component; etc.). In a

Table 6.1

Frequency of Use of Material Type Names

Name	No. of Occurrences	Name	No. of Occurrences
A	135	MO99	125
A1	171	MOTC	23
A3	324	NA24	60
AG110	20	N163	1406
AMBE	219	NLS	36
AM241	1967	NPA	274
AU198	78	NP237	55
BA133	129	PM147	114
CA45	210	PO210	153
CD109	197	PU238	296
CE141	33	PU239	232
CF252	130	PU, PUU, PU1	99
CL36	104	PUBE	143
CM244	85	P32	587
CO60	1464	P33	52
CR51	256	RB86	54
CSAM	237	SB124	22
CS137	3212	SC46	32
CU64	28	SE75	53
C14	839	SN113	38
DU	357	SR85	42
FE55	177	SR90	600
FE59	157	S35	403
GD153	37	TC99	85
GR1	1970	TC99m	107
GR2	1995	TH, THU, UTH	111
GR3	1914	TH228	32
GR4	1050	TH232	34
GR5	796	TL204	53
GR6	445	TYPB	20
HG203	48	TYPC	19
H3	1521	U233	49
IR192	484	U235	168
I125	827	U238	113
I129	67	U, UUR, UND	70
I131	953	VIT	1141
KR85	291	XE133	1265
K42	55	YB169	27
MN54	40	ZN65	78

Totals	Names	Entries
This List	78	31293
Total File	609	32574

(greater than 96% coverage)

Table 6.2

Frequency of Use of Configuration Abbreviations

Name	No. of Occurrences	Name	No. of Occurrences
A	7572	LPT	29
ADY	21	MET	77
ALY	21	MTG	31
AXB	21	OXD	25
BFP	1036	PAS	29
BNA	26	PLM	27
CAL	40	PLS	200
CAR	31	PPK	149
COE	20	PSD	181
CPM	207	SDS	59
CSC	31	SLD	24
ENC	138	SLS	30
FDC	956	SNS	442
FOI	358	SOL	97
FPD	30	SPS	21
FPS	35	SS	8877
FSS	36	SSS	47
GAS	148	STF	29
GEN	36	TTF	144
HYP	301	TTT	21
IOD	89	UDC	107
IRM	27	-	9574
LIQ	32		

Totals	Names	Entries
This List	45	31432
Entire File	388	32549

(greater than 96% coverage)

hazards assessment, the integrity of a sealed source in an adverse environment is important. A distinction might be made between those with substantial containment (e.g., double encapsulated) and those just sealed (e.g., plated).

In the Part 70 licenses, there are currently 35 names indicating different degrees of enrichment; some of these differ by only 0.02 percent. A few simple categories, such as the following:

	U235 Percentage
Depleted	< 0.2%
Natural	< 0.7%
Low Enriched	> 0.7%, < 5%
Medium Enriched	> 5%, < 20%
Medium-High Enriched	> 20%, < 50%
High Enriched	> 50%

could be used to make the data base easier to understand and less subject to misinterpretation.

A number of inconsistencies, ambiguities, and errors were found in the initial screenings of the data base. These can generally be classified as follows:

- Stable, naturally-occurring nuclides (CL35, CO59, CR52, IN113, IR193, SN119, SR87, TE125, S34, XE131).
- Naturally-occurring nuclides with very long half-lives (K40-10^9y, CD113-10^{15}y, TE123-10^{13}y).
- Unrealistic nuclides (AR45, CO65, TL170, RB106).
- Very short-lived nuclides, without corresponding parents. (TC99M, PT183, PO218, AM246, FE51, ...).
- Single nuclide of mixture: The principal example is U235, without specifying the U234 fraction, which usually dominates the inhalation hazard.
- Possession limit specified with too many (eight or more) significant digits.
- Nuclides which the NRC does not have the statutory authority to regulate (isotopes of actinium, protactinium, etc.).

Over time, license reviews and inspections should resolve and/or correct most of these cases.

A thorough review and simplification of the terminology used for the possession limit descriptions, so as to identify a minimum set needed for the Licensing Management System and the licenses, would significantly enhance user comprehension, and reduce learning time and data entry error rates. If a simpler and more concise dictionary were adopted, a descriptive field could be added to provide any supplemental information that might be appropriate or important. Such a system would be easier to use and understand. This work is in progress under a separate NRC program.

6.2 Screening Methodology

The central basis for the initial evaluation of a licensed facility is that the estimates of dose at a selected distance arising from postulated accidents do not exceed exposure guidelines. In simple terms, the dose to an individual is a product of (1) quantity of material involved, (2) release fraction, and (3) the unit dose estimate for the nuclide considered (Table 5.1). Since several dose criteria are used (effective dose equivalent, and thyroid, kidney and bone surface doses), the ratio of the estimated dose to the respective criterion is a measure of the potential hazard. For licenses with multiple nuclides, the sum of the individual ratios is the corresponding measure. This can be expressed as:

$$\sum_{\substack{\text{all} \\ \text{radionuclides} \\ i}} \frac{(Qpl)_i \ (RF)_i \ (Ds)_i}{(Dc)_i} \leq 1 \qquad (6.1)$$

where

Qpl = licensed possession limit

RF = release fraction

Ds = dose estimate for a specified unit release

Dc = exposure dose criterion

and wherein the sum is less than one for releases which would not exceed the criteria. If the sum exceeds one, then, based on the assumptions used, the accidental exposures might exceed one of the exposure criteria.

A computer program was written to implement this screening method. Algorithms for processing the isotopes in group medical licenses and broad licenses are included. The contribution to the sum from each material type is listed in the output. The release fractions and unit dose estimates

are handled as separate input files, so they may be easily changed.

For the group medical licenses, isotopes and reasonable upper bounds for possession limits were assigned for each group. These assignments are listed in Appendix B. The assigned possession limits are used in Equation (6.1) if no quantity is listed in the data base; otherwise, the quantity from the data base is used.

Rules for handling the broad scope (A Any) licenses get quite complex. The "any" designation can be followed by a number of exceptions. The quantities listed for the "exception" isotopes may be higher or lower than that listed for the "any" material type. First, lists of isotopes were developed for the several types of "any" material types. In general, the nuclides selected were those with the highest effective dose equivalent values (from Table 5.1). These assignments are listed in Table B.6. If the license has no exceptions associated with the "any" material type, then the first 10 isotopes in the list are used in performing the sum. If there are exceptions, then the first 10 among those not so excepted are used. A few special "any" types have only one assigned nuclide; these are listed at the bottom of Table B.6. These rules for the "any" material types are more fully explained in Appendix B.

As noted earlier, there are two different ways that quantities are listed for sealed sources. If a total possession limit is given, it is simply used. If the entry is for an unlimited number of sources of a specified size (the /0 designation), then the activity for one source is used in performing the sum (Equation 6.1).

The dose contribution for Iodine-129 was calculated in a special manner. Due to the limited capacity of the thyroid for the uptake of iodine and the low specific activity of Iodine-129, there is a practical limit on the dose that could be received from an arbitrarily large exposure to this nuclide. Based on data from an NRC memo (USNRC, 1984a), the Iodine-129 thyroid dose was not allowed to exceed 0.5 rem.

In the output listing, the contribution to the sum for each entry (material type, configuration, quantity) is listed, as is the total sum. If 90 percent or more of the total comes from one material type which has a sealed source configuration, then that license is so identified (*). A sample of this output listing from the screening program for two licenses is shown in Figure 6.1.

In performing the screening, the licenses are sorted into a number of general categories, depending on the configuration, use of the /0 quantity designation for sealed sources, etc., and are then ordered by the magnitude of the

```
030-04581 20-00320-13        24      PLDB5       83/08/04.
  A3        A   10CI/500  0.0000  .138E+01 10 USED, SET 2, QUAN .100E+02
  CA45      A   0/50CI     .0100  .580E-03
  C14       A   0/500CI    .5000  .950E-01
  CE141     A   0/50CI     .0100  .810E-03
  CS134     A   0/25CI     .0100  .220E-02
  CS137     A   0/500CI    .0100  .300E-01
  CR51      A   0/100CI    .0100  .740E-04
  AU198     A   0/200CI    .0100  .152E-02
  I125      A   0/100CI    .5000  .140E+01
  I131      A   0/25CI     .5000  .475E+00
  FE55      A   0/200CI    .0100  .960E-03
  KR85      A   0/10000C  1.0000  .320E-03
  NI63      A   0/1000CI   .0100  .112E-01
  P32       A   0/500CI    .5000  .700E+00
  RB86      A   0/50CI     .0100  .620E-03
  RU103     A   0/25CI     .1000  .450E-02
  SE75      A   0/100CI    .0100  .168E-02
  SR90      A   0/500CI    .0100  .110E+01
  S35       A   0/1000CI   .5000  .220E+00
  TM170     A   0/25CI     .0100  .115E-02
  SN113     A   0/100CI    .0100  .200E-02
  YB169     A   0/50CI     .0100  .780E-03
  A83X      A   0/10MCI   0.0000  .720E-01  1 USED, SET 1, QUAN .100E-01
  AM241X    SS  0/350CI    .0005  .287E+02
            LICENSE TOTAL =    .342E+02

070-00572 SNM-567            17      ORIGINAL    83/02/10.
  PU236     A   0/199G     .0100  .508E+05
  A3X       A   2CI/0     0.0000  .199E+00 10 USED, SET 2, QUAN .200E+01
  CS137X    A   0/200CI    .0100  .120E-01
  TM170X    A   0/10CI     .0100  .460E-03
  CM243     A   0/10CI     .0100  .108E+02
  CO60X     A   0/50CI     .0100  .200E-01
  SR90X     A   0/50CI     .0100  .110E+00
  TL204X    A   0/50CI     .0100  .220E-03
  SB124X    A   0/50CI     .0100  .260E-02
  BI210X    A   0/50CI     .0100  .170E-01
  PM147X    A   0/70CI     .0100  .462E-02
  PO210     A   0/3000CI   .1000  .456E+03
  NP237     A   0/100MCI   .0100  .156E+00
  AM241     A   0/6000CI   .0100  .984E+04
  CM242     A   0/600CI    .0100  .192E+02
  CM244     A   0/600CI    .0100  .516E+03
  CF252     A   0/10MG     .0100  .173E+01
            LICENSE TOTAL =    .617E+05
```

Figure 6.1. Sample Output of Screening Program (Major columns showing material type, configuration, possession limit, release fraction and contribution to the total).

sum. With these categories, the contributions from sealed source versus other configurations can be compared. Decade steps are used to rank those exceeding the base criterion (Sum≥1). The magnitude by which the various numbers of licenses are over the limit can then be conveniently displayed. For the results, however, these categories are condensed to simply the total number of licenses in each decade and the number for which the sum is not dominated by one sealed source. (The latter is a subset of the former.)

6.3 Preliminary Screening Results

The screening analysis program used the computer data base of radionuclide license possession limits, assigned sets of release fractions, and the unit dose estimates for each radionuclide (from Chapter 5). The principal assumptions in this evaluation process are summarized as follows:

1. The source term for each radionuclide is the product of the licensed possession limit and the corresponding release fraction.

2. The unit dose estimates (described in Chapter 5) are the 99th percentile results from a frequency distribution constructed from results for a full range of meteorological conditions. These doses are peak center line, ground-level estimates for a distance of 100 m from the release point.

3. Two dose criteria were used: 1 rem EDE and 5 rem EDE. These values represent the lower and upper ends of the range for considering the implementation of protective action. The corresponding thyroid dose limits are 5 rem and 25 rem. For the 5 rem EDE criterion, other organ doses (see Tables 5.3 and 5.4) must be included, for which the limit is 50 rem.

Two dose levels for the screening criterion were used to examine the sensitivity of the results to the criteria selected. In combination, these provide considerable assurance that, for the assumption used, the screening results are a bound and would, in most cases, be quite conservative.

The screening analysis program was run separately for the Part 30 and 70 licenses. There is also a group of 460 licenses for which the docket numbers are not known; these are designated Part 00. For each type, the licenses were ordered by the magnitude of the sum, as discussed in the previous section. The number of facilities whose sum is in each decade range (1-10, 10-100, etc.) can then be presented in a cumulative fashion in the tables of results by stating the number for which the sum exceeds 1, 10, 100, etc. The following results are for Parts 30, 70, and 00.

The results for Part 40, source material licenses, are discussed separately.

For the screening analyses, the individual radionuclides were divided into six groups for the purposes of assigning release fractions. They are based on generally expected volatility in accident environments (especially fires), with three common neutron source materials in a separate group:

1.	Volatile gases	H3, AR, KR, XE
2.	Volatile, combustible	C, P, S, I
3.	Semivolatile	BR, RU, TE, HG, PO
4.	Inert metals	CO60, TA, W, OS, RE, IR
5.	Neutron source matl's	PU238, PU239, AM241
6.	All Others	All other nuclides

Then for each group, two release fractions are assigned, one for nonsealed source forms and one for sealed sources.

In the first series of screenings, the groups were examined one at a time, considering only nonsealed source forms. The following table lists the number of licenses which exceed the base criterion (sum=1). For each group considered, the release fractions for the other groups were set to zero, thereby excluding their contribution.

Group		Release Fraction	Number of Facilities	
			1 rem EDE	5 rem EDE
1.	H3, AR, KR, XE	1.0	14	2
2.	C, P, S, I	0.5	33	11
3.	BR, RU, TE, HG, PO	0.1	25	6
4.	CO60, TA, W, OS, RE, IR	0.01	14	4
5.	PU238, PU239, AM241	0.01	84	64
6.	All other nuclides	0.01	108	79

Since these screenings were all for nonsealed source forms, the release fractions for all nonvolatile nuclides (Group 6) were the same.

In the "all other" group, about 60 percent of the 108 licenses identified were "any" type licenses; that is, the license authorizes possession of any nuclide, depending on the specifications of the license, up to the amount allowed. There are two reasons that these licenses were identified. The first is the radionuclides that were assigned within the screening program for use in computing the sum Equation (6.1). In general these were the nuclides with the highest specific dose estimates (from Tables 5.1 and 5.2). Since the licensee can possess any nuclide within the specification of his "any" category, without further approval by

NRC, it was felt that the nuclide assignments should be conservative for the initial screening. Further examination of specific licensees should use supplemental information available in the docket file, license application or from the licensee, but which is not available in the possession limit data base. The second reason is that a few licenses authorize very large quantities of material; for example, 22,000,000 Ci, 6803 kg, etc.

The next set of screenings examined the nonsealed source forms of all six groups together. The release fractions were the same as above. The total number exceeding the indicated criterion are as follows:

	1 rem EDE	5 rem EDE
Sum > 1	186	134
> 10	99	79
> 100	56	45
> 1000	32	21
> 10000	17	14

In each screening the entire set of nonsealed source release fractions was used, not each group separately.

The sensitivity of the number of facilities to the PU/AM release fraction was examined by using the above set of release fractions and 1 rem EDE, but with release fractions for Group 5 of 0.005 and 0.02. The number of facilities identified was 178 and 200, respectively; not a significant change from 186.

Another series of screening runs were made to identify the number of additional licenses that might exceed the criteria due to possession of sealed sources. For nonsealed source forms, the release fraction set above was used; this set remained constant for all runs. For each run, a nonzero release fraction was assigned for sealed sources of each group in turn, as follows:

	Group	Sealed Source Release Fraction	Additional Facilities 1 rem EDE	Additional Facilities 5 rem EDE
1.	H3, AR, KR, XE	1.0	8	1
2.	C, P, S, I	0.5 combined with group 1		
3.	BR, RU, TE, HG, PO	0.01	4	0
4.	CO60, TA, W, OS, RE, IR	0.0001	16	12
5.	PU238, PU239, AM241	0.001	447	323
6.	All other nuclides	0.005	17	14

For Groups 1 and 2, the sealed source release fractions were the same as for nonsealed source forms. For Groups 3 through 6, they were set at a factor of 10 to 100 smaller than the corresponding nonsealed source release fraction.

Finally, screenings were performed using complete (non-zero) sets of release fractions for both nonsealed source forms and sealed sources. The release fractions are as follows:

Group	Release Fractions Non-SS	SS
1. H3, AR, KR, XE	1.0	1.0
2. C, P, S, I	0.5	0.5
3. BR, RU, TE, HG, PO	0.1	0.01
4. CO60, TA, W, OS, RE, IR	0.01	0.0001
5. PU238, PU239, AM241	0.01	0.0005
6. All other nuclides	0.01	0.001

The results are presented for the total number of facilities exceeding the criterion and also the number of facilities over the limit due to nonsealed source forms (or small sealed sources). For the two screening criteria, the results are:

	1 rem EDE		5 rem EDE	
	Total	Non-SS	Total	Non-SS
Sum > 1	672	248	480	170
> 10	342	114	277	92
> 100	209	69	99	48
> 1000	47	34	26	22
> 10000	22	18	17	14

In these runs each license was examined to see if more than 90 percent of the sum was due to the possession of one material type in sealed source form. If so, it was categorized as a "sealed source license." The number of nonsealed source licenses was then simply the total less the number of "sealed source licenses." Hence small sealed sources could contribute (but usually only to a small degree) to the sum for those categorized as nonsealed source.

The distribution by docket category of the licenses identified as exceeding the limit for release fraction set above and for the 1 rem and 5 rem EDE limits is as follows:

Docket Category	1 rem EDE	5 rem EDE
Part 30	334	210
Part 70	311	259
Part 00	27	11

The majority of the large sealed sources are licensed under Part 70.

The Part 40 Source Material licenses were not included in the above screenings because of the very low specific activity of these materials and the large uncertainty in selecting an appropriate source term applicable for all Part 40 licenses. A number of site-specific factors and assumptions could strongly influence an initial screening of these facilities. To use the licensed possession limits (the only information available for all Part 40 licenses) for source materials seemed overly conservative. These caveats aside, two screenings of the Part 40 licenses were done. The relevant release fraction of the set is the 1 percent for nonsealed source forms of uranium and thorium. The screening of the 252 licenses identified 58 of them as being over the limit using a 5 rem EDE criterion, and 93 licenses for a 1 rem EDE criterion, which reinforces the statements above concerning the importance of selecting an appropriate and realisitic source term.

For the results of one screening, using the 1 rem limit, the program or license code category for each identified license was obtained from the December 1982 version of the master file. The number of licenses in each category were counted and the results are listed in Table 6.3. It is recognized that this version of the master file uses the "old" program codes, and not the "new" codes, which provide for finer distinctions between licenses. It is felt that the old program codes are sufficient for this initial screening.

The ordering of the licenses by the magnitude of the sum provides a way of allocating resources in later reviews and evaluations. Those with a very large hazard potential can be evaluated individually and in relative detail. At the low end ($1 \leq \text{sum} \leq 10$), consideration of groups of licenses by generic characteristics (e.g., chemical form, methods of storage, facility safety systems, distances greater than 100 m, etc.), could remove from further consideration significant numbers of these licenses. Additionally, factors not considered explicitly in this study could be identified and employed in optimizing the evaluation process.

Further consideration of licenses with one or more large sealed sources involves the evaluation of accidents with potentially large effects, but with historically very low occurrence rates. This initial screening shows there could be as many as 300 such licenses under Parts 30 and 70. The emergency response planning process, and even the criteria which establish the need for such a process, could be different than for other licenses. Certainly, sealed sources which meet rigid design, construction and quality assurance standards, for example as in 10 CFR 70.39, would seem to

Table 6.3

Program Codes for the Set D Screening Results

Code Number	Code Title	No. of Licenses
Part 30		
01-100	Academic--Broad	24
01-200	Academic--Other	48
02-110	Institutional--Broad	17
02-120	Institutional--Other	6
03-110	Well Logging	49
03-120	Other Measuring	40
03-211	M, D & S--Broad	13
03-212	M, D & S--Other	26
03-232	Waste Disposal	8
03-400	Power Sources	5
03-520	Irradiator, $< 10^4$ Ci	13
03-610	R & D, Broad	37
03-620	R & D, Other	20
-	Other categories or none listed	28
Part 40		
11-200	Other, > 150 kg	15
11-300	Other, < 150 kg	112
-	Other categories or none listed	13
Part 70		
21-230	Fuel Fabrication--Uranium	6
21-240	Other uses inc. R + D (Uranium)	10
22-120	Neutron Sources	132
22-150	Other SNM (noncritical)	9
22-160	Institutional Cardiac Pacemakers	87
22-200	Uranium	11
23-100	Fuel Storage	5
-	Other categories or none listed	51
Part 00		
-	Other categories or none listed	27

pose less of a risk of rupture and release of contents in severe accident environments than sources not meeting such standards. However, the proliferation of terminology for "sealed" in the possession limit data base and on the licenses themselves does not allow a clear and unambiguous assessment of all sealed sources in this initial screening analysis.

CHAPTER 7

Emergency Planning and Response

In considering emergency response to accidental releases of radioactive materials from fuel cycle or by-product material facilities, the principal hazards requiring immediate response are significant airborne radionuclide releases. Because of the suddenness of the releases and the relatively short distances involved, little time would be available to implement measures for dose avoidance. The entire sequence of events, (accident, release, atmospheric transport, and exposure) would often take less than a few tens of minutes for inhalation and external air exposures. For these releases, immediate sheltering is the only viable protective action.

For those radionuclides for which the ground exposure pathway is a large contributor or dominates, timely emergency response is apt to be more effective. In the CRAC2 calculations discussed in Section 4.1 and dose results presented in Chapter 5, an individual was assumed to be exposed to contaminated land for 8 hours, at which point evacuation to an uncontaminated area was assumed to have occurred. The dose from the ground exposure pathway is roughly proportional to the exposure time.

The radionuclides with significant ground exposure doses are generally different from those that are important in considering direct plume exposures. Hence, the methods for predicting the size of planning zones and the potential protective actions could be different.

At the slow end of the time scale, spills, potential ground water contamination and chronic, long-term releases could require months to years for significant radiological dosages to be received by the exposed population. Due to the long times available for surveillance, monitoring, assessment, and response, these releases are not considered.

An Emergency Planning Zone (EPZ) is an area around a licensed facility within which it is expected that emergency actions might be needed following an accidental release of radioactive material, so as to reduce or mitigate the radiological exposure of the public. These zones could be offsite with respect to land owned or controlled by the licensee, and hence could be occupied or used by members of the general public on an unrestricted basis.

As discussed in the previous chapters, a number of factors, parameters, and variables can influence the dose received by an individual located at some distance from the plant. These can be summarized in three categories:

1. Characterization of the Release
   - Quantity
   - Chemical and Physical Forms
   - Duration

2. Atmospheric Transport and Dispersion
   - Variability due to Weather
   - Distance
   - Building Wake
   - Release Height
   - Buoyancy (Heat)

3. Dosimetry
   - Dose Contributions from Inhalation, External Ground Exposure, and External Cloud Exposure
   - Biological Clearance Rates.

A fourth category influencing the dose is dose avoidance and mitigation measures, which could be implemented in response to the accidental release.

As part of the preaccident planning for a facility, estimates are made of the radiological effects of serious accidents. If significant doses could occur in areas occupied by the general public, then the need for and potential effectiveness of emergency planning and preparedness should be further evaluated. An emergency planning zone could then be established for those areas in which the dose might be expected to exceed levels warranting the implementation of emergency protective actions. For a specified release, the distance at which the estimated dose would not exceed that specified in a protective action guide can be calculated; or inversely, if the distance is predetermined by other considerations (i.e., site boundary distances, major topological features, etc.), the size of a maximum release can be estimated, such that a guideline dose level is not exceeded. Other factors involving the specific site under consideration, such as adjacent land use, population distribution, predominant wind directions, plant processes, inventory quantities, etc., should be factored into the establishment of planning zones.

This study concentrates on the effects of and responses to airborne plume releases and initial ground deposition. Methods are suggested for calculating the extent of areas within which the dose is estimated to be above selected levels for airborne releases (Section 7.1) and for long-term ground exposures (Section 7.2). Dose avoidance and mitigation measures are discussed in Section 7.3.

7.1 Zones for Atmospheric Plume Exposures

A simple method has been developed for estimating the distance out to which a postulated release could lead to doses above selected guideline exposure levels. It is based on a simplification of the dose versus distance data in Table 5.1 for all of the radionuclides. The two principal factors in this data are first the specific dose conversion factors for each radionuclide, and second a dilution factor representing the decrease in concentration with distance. However, complicating factors, like the multiple exposure pathways and the varying weather sequences that contribute to the relevant part of the distribution, do not allow a simple, first principles derivation of the dilution factor.

If one were to plot the dose versus distance data in Table 5.1, it would be seen that only three curve shapes would result, one for noble gases, one for tritium, and one for all other nuclides. The individual nuclide curves would of course be distributed along the vertical axis due to the differing dose conversion factors. This suggests that a distance factor can be defined that is normalized to one (1) at a distance of 100 m:

$$\text{Distance factor} = \frac{\text{Dose (distance} > 100\text{ m)}}{\text{Dose (distance} = 100\text{ m)}} \quad .$$

In Figure 7.1, the resulting distance factors, one for noble gases, one for tritium, and one for all other radionuclides, are plotted. The tritium curve is different from the one for noble gases because the dose for tritium is due to inhalation, while that for the noble gases is due to cloudshine.

This distance factor could then be used to estimate a distance beyond which the estimated dose would not be expected to exceed a selected exposure level. Using the upper end of the range from the Protective Actions Guides as an example, this can be expressed as:

$$\begin{pmatrix}\text{Curies}\\ \text{Released}\end{pmatrix} \times \begin{pmatrix}\text{Unit dose}\\ \text{at 100 m}\end{pmatrix} \times \begin{pmatrix}\text{Distance}\\ \text{Factor}\end{pmatrix} < \begin{cases}5\text{ rem EDE or}\\ 25\text{ rem thyroid or}\\ 50\text{ rem other organ.}\end{cases}$$

Once the isotope and the release size are specified, then the Distance Factor that is needed to satisfy this relationship can be calculated. A factor greater than one implies a distance of less than 100 m. Actions required within such a short distance can best be implemented directly and immediately by the licensee. A factor that is less than 0.15 for noble gases, or 0.04 for tritium, or 0.02 for the other

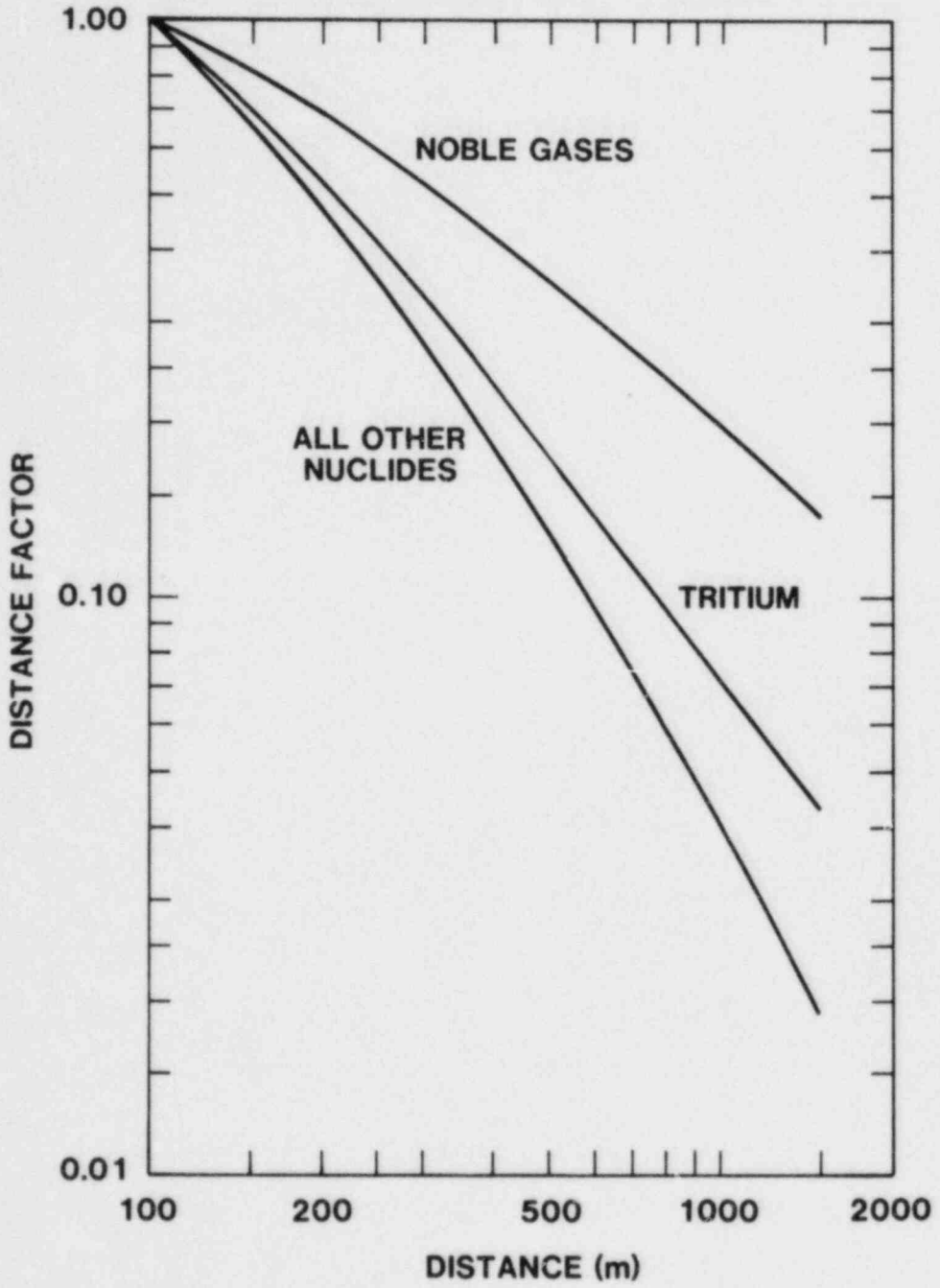

Figure 7.1. Distance Factor. Ratio of Dose at > 100 m to the Dose at 100 m.

nuclides, implies a planning zone of greater than 1500 m, the largest distance considered in the dose calculations. Accident and safety analyses that indicate such a large zone for a by-product material licensee should carefully consider all factors in the analysis and planning processes so as to find the best ways of assuring protection of public health and safety. Source control and augmented in-plant accident mitigation systems may be more effective than external emergency response planning.

The time available for dose avoidance measures to be effective for the direct plume exposure pathway is quite short. As discussed in Section 3.1, the dose at the 95th percentile and above for an inhalation dominant radionuclide generally corresponds to a windspeed of about 1-2 m/s. At a distance of 500 m from the release point, the time available for the implementation of protective measures would be less than 10 minutes (or correspondingly longer for extended release durations). However, the average windspeed for non-precipitation weather conditions is on the order of 5 m/s; this roughly corresponds to the 50th percentile dose. Thus, if an average dose (as compared to a 95th percentile dose) is to be avoided, only 1 to 2 minutes would be available if dose avoidance protective actions are to be effective.

7.2 Ground Contamination Zones

Once the plume from an accidental release has dissipated, continued long-term exposure to the contaminated ground could, for some radionuclides, still result in a significant dose. In the short term (hours to days), surveillance, monitoring, and assessment of the extent and magnitude of the contamination will be needed to identify appropriate responses. The chronic or long-term ground exposure pathway includes direct external exposure from the contaminated ground, inhalation of resuspended radionuclides, ingestion of crops and foods grown on contaminated soil, and consumption of contaminated water sources.

Considerable variability in local conditions will lead to wide variations in the estimated dose to an individual occupying the contaminated region. These factors include:

- Chemical and physical form of the released radionuclides;
- Site meteorology and plume depletion;
- Local soil conditions;
- Weathering and environmental dilution; and
- Land uses.

While global or blanket assumptions could be made for planning purposes so as to roughly estimate a dose, the uncertainty in these factors and conditions could affect the dose estimates by many orders of magnitude for any individual accident.

If one were to base planning zones for ground contamination on such potential dose estimates, they would show about the same large variability due to the above factors and conditions, particularly size of the release, environmental weathering, extent of land use, and to a lesser extent, the plume depletion rate (which depends on particle sizes of the released radionuclides). Note that such a planning zone is based on dose estimates from a distribution covering a full range of meteorological conditions. The distance to which land becomes contaminated as a result of an actual, single accident could be quite different, due to the actual weather conditions at the time of the accident. Since the doses in Table 5.1 are for the 99th percentile, it is expected that an actual distance would be smaller 99 percent of the time, with a 1 percent chance of being larger.

A simpler method for establishing the size of this planning zone would be to base it on estimates of the initial ground contamination level (Ci/m^2) rather than on dose estimates. Such a zone depends principally on the size of the release and the plume depletion rate, and is independent of long-term environmental effects.

The dependence on particle size of the deposition rate from a plume is shown in Figure 3.3. For small particles, high diffusion rates lead to contact with and absorption by the ground. Above about 2 microns, gravitational settling dominates. Ground contamination levels could vary by approximately a factor of 2 (and may be as high as a factor of 10) for a reasonable range of expected particle sizes. In the CRAC2 atmospheric dispersion calculations, a 1 micron aerosol was assumed.

Many other factors influence the time dependence of the resulting ground contamination level, such as soil type, ground cover, past land use, soil leaching, weathering and environmental dilution (wind and rain), etc. However, the initial level is independent of these and depends principally on the size of the release and the deposition rate.

The screening results indicate that the largest number of potentially affected licenses would be those authorizing possession of alpha emitters, principally plutonium and americium. These nuclides have little contribution to the external dose (groundshine); however, resuspension and subsequent inhalation could lead to significant chronic doses, especially for extended occupation of the land. For

plutonium, a criterion has been specified for ground contamination levels above which decontamination efforts are recommended for unrestricted land use. This level is 0.2 $\mu Ci/m^2$ (EPA, 1977). Since the decay energy for most alpha emitters is roughly the same, it would not be inappropriate to use this level for most such radionuclides as a first approximation. Similar criteria for radionuclides other than alpha emitters (e.g., ^{60}Co, ^{137}Cs), upon which to base the initiation of protective actions, have not been established.

As an example, ground contamination levels for a 1-curie release of a (particulate) radionuclide are given in Figure 7.2 for deposition velocities of 0.1 and 1.0 cm/sec. Based on the data in Figure 3.3, the latter value corresponds to approximately five to ten micron particles, usually regarded as an upper limit for aerodynamically transportable and respirable particles. The smaller rate corresponds to particle diameters of a few microns or a few hundreths of a micron, as shown in Figure 3.3. The ground contamination levels scale with the size of the release. These curves can be used, along with the size of the release, to provide a bounding estimate of the extent to which land might be contaminated above the 0.2 $\mu Ci/m^2$ level and for which decontamination or interdiction efforts may be warranted.

After an actual accident at a specific site, radiological surveys of the surrounding areas would be the best way of assessing the extent of ground contamination. Modeling estimates would be highly dependent on exact knowledge of local meteorological conditions during the accidental release. Since such detailed knowledge would probably not be available or would have a large uncertainty, field surveys of actual ground contamination would be much more reliable.

7.3 Dose Avoidance and Mitigation

In the event of a significant airborne release, potential emergency responses can be subdivided into two general categories, dose avoidance and dose mitigation. Examples of the former include sheltering and evacuation. Mitigation measures include medical treatment to impede the uptake of radionuclides or hasten their removal from the body or organs therein.

The critical factor in dose avoidance for most of the release scenarios and subsequent exposures considered in this study is the minimal time available for effective actions. Even assuming slow wind speeds (e.g., 1 m/s), the cloud would expose an individual at 500 m in less than 10 minutes (or the sum of 10 minutes plus the release duration for plume releases). Actions within this time period would have to include initial assessment of the release and wind direction, notification of the affected population, and

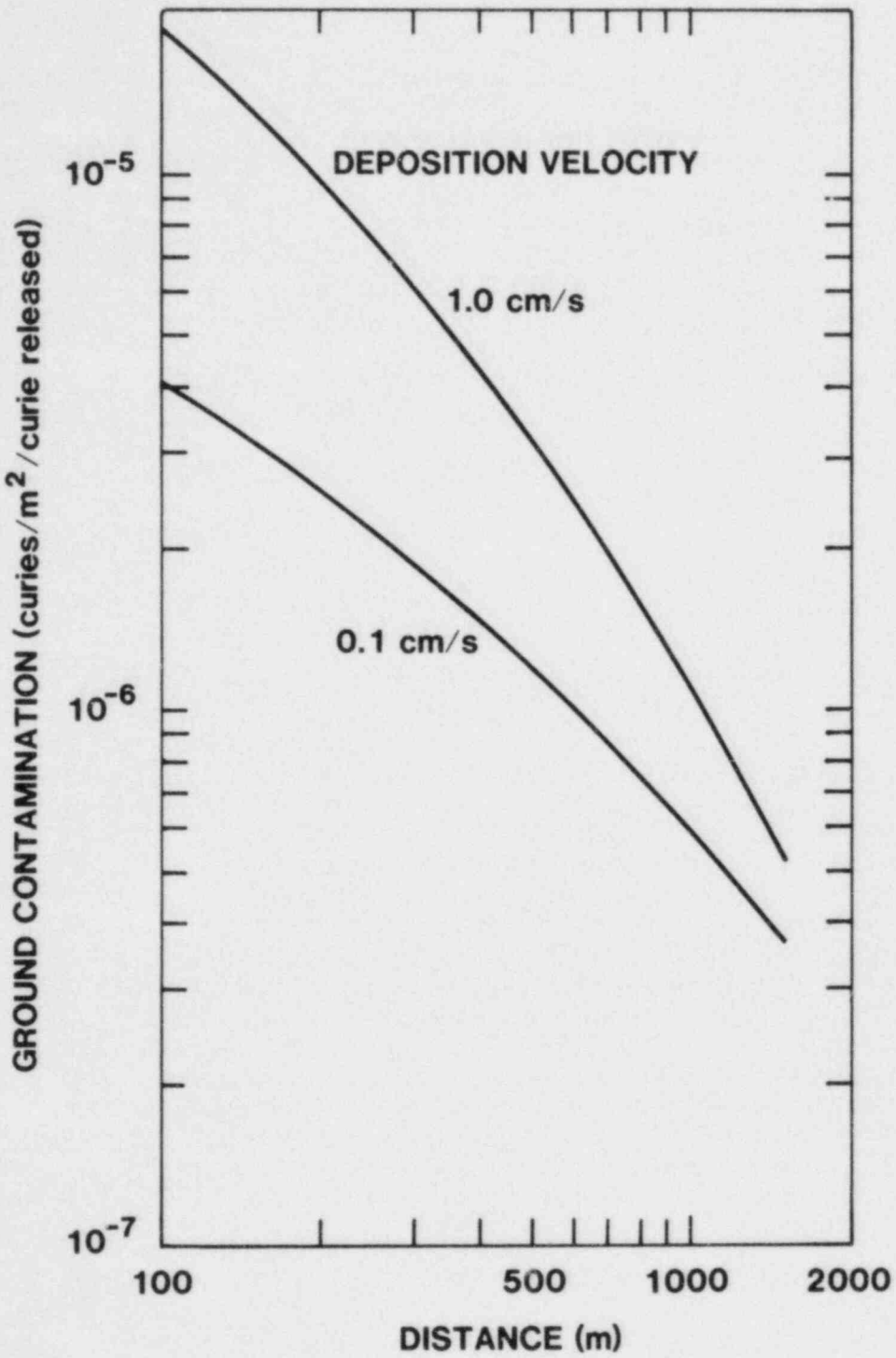

Figure 7.2. Ground Concentrations (99th Percentile) as a Function of Distance for a 1 Curie Release

finally, implementation of protective measures. In general, sheltering (as compared to evacuation) may be the only viable action, especially when a significant number of people are involved.

As discussed earlier, emergency actions could be effective for releases of isotopes for which the immediate ground exposure dominates. Sheltering or evacuation, or a combination of the two, could be effective in the short term. Evacuation would be the more effective of the two if adequate planning is done and sufficient transport resources are available.

Given that the release is detected, a key part of the emergency response is notification of the potentially exposed population. The effectiveness will depend on the land uses and population distribution within the EPZ. Planning for adequate notification is crucial for dose avoidance measures to be effective.

In Table 7.1, the various measures or actions that could be effective for the three dose pathways are listed. In general, they are listed in order of effectiveness.

The fractional contributions to the dose from each pathway for each radioisotope are given in Table 5.3. In general, one pathway dominates for each nuclide. For the few radioisotopes with more than one significant pathway, a combination of actions may be warranted. This contribution information may be useful in the planning process for considering accidents involving individual radionuclides at specific individual facilities.

A recent report, "Preparedness and Response in Radiation Accidents" (Shleien, 1983), from the National Center for Devices and Radiological Health, comprehensively summarizes the planning and response efforts needed to cope with radiation accidents. The emphasis is on reactor accidents, but many of the subjects covered are applicable to accidents at by-product material facilities. Topics include organization and planning, radiation protection, contamination, monitoring, protective actions, medical responses, training, etc.

Decontamination is a dose avoidance action for chronic ground exposures. Once immediate actions have been taken (e.g., sheltering/evacuation), and area surveillance and monitoring has been done, an assessment can be made of the costs and benefits of decontamination. An alternative is land interdiction or withdrawal until such time that radioactive decay, and environmental weathering and dilution have achieved the same level of decontamination.

Table 7.1

Protective Actions

Exposure Pathway	Dose Avoidance	Dose Mitigation
External Air	Sheltering Evacuation	None
Inhalation	Sheltering Evacuation Breathing filter	Medical treatment for uptake blockage or isotope removal
Ground		
Ground shine (γ emitters)	Initial sheltering (for acute exposure) followed by evacuation (for chronic exposures)	None
Resuspension/ Inhalation (α emitters)	Evacuation	Medical treatment
Ingestion (chronic, long-term)	Crop and drinking water interdiction	Medical treatment

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APPENDIX A

Internal and External Dose Conversion Factors

The effective dose equivalent values are presented in Table A.1 for the inhalation, external ground, and external cloud exposure pathways. In constructing these, the dose equivalent values for 22 body organs from inhaled radionuclides from ICRP Publication 30 (ICRP, 1979a; 1979b; 1980) were taken from a data tape provided by K. Eckerman, ORNL. The external dose factors from NUREG/CR-1918 (Kocher, 1981) were taken from a data tape provided by D. Kocher, ORNL. The organs used to define the remainder category are listed in Table A.1 for each radionuclide and exposure pathway.

The inhalation effective dose equivalents are expressed as rem per curie inhaled. The effective dose equivalents for the external cloud exposure are expressed as rem·m^3/Ci·sec and the effective dose equivalents for the external ground exposure are expressed as rem·m^2/Ci for an 8-hour exposure interval. In addition, the thyroid dose equivalent values are presented for each radionuclide and exposure pathway. The units for the thyroid dose are the same as those listed above.

Table A.1

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
H 3		INHAL	1.24E+02	SI+CONT	HEART	BRAIN	BLAD WAL	ADRENALS	1.24E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
C 14		INHAL	2.08E+03	ULI WALL	SI+CONT	BRAIN	BLAD WAL	ADRENALS	2.06E+03
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	6.82E-06	NONE	NONE	NONE	NONE	ADRENALS	0.
F 18	D	INHAL	8.26E+01	THYMUS	SPLEEN	ADRENALS	PANCREAS	S WALL	1.27E+01
		EXTGRD	2.94E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.13E+01
		EXTCLD	1.58E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.68E-01
NA 22	D	INHAL	7.62E+03	UTERUS	KIDNEYS	SI+CONT	LLI WALL	ADRENALS	5.86E+03
		EXTGRD	1.91E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.07E+02
		EXTCLD	3.55E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	3.85E-01
NA 24	D	INHAL	1.20E+03	LIVER	ADRENALS	THYMUS	PANCREAS	S WALL	5.60E+02
		EXTGRD	2.76E+02	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	2.84E+02
		EXTCLD	7.60E-01	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	7.96E-01
MG 28	W	INHAL	4.88E+03	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	3.92E+02
		EXTGRD	2.42E+02	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	2.47E+02
		EXTCLD	5.42E-01	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	5.79E-01
SI 31	D	INHAL	2.17E+02	ADRENALS	LLI WALL	S WALL	SI+CONT	ULI WALL	1.66E+01
		EXTGRD	3.00E+00	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	3.33E-02
		EXTCLD	1.51E-03	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	1.59E-04
P 32	W	INHAL	1.54E+04	ADRENALS	SI+CONT	S WALL	ULI WALL	LLI WALL	1.23E+03
		EXTGRD	8.53E+00	ADRENALS	SI+CONT	S WALL	ULI WALL	ADRENALS	0.
		EXTCLD	1.62E-03	ADRENALS	SI+CONT	S WALL	ULI WALL	ADRENALS	0.
P 33	W	INHAL	2.30E+03	ADRENALS	SI+CONT	S WALL	ULI WALL	LLI WALL	1.85E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	4.48E-05	NONE	NONE	NONE	NONE	ADRENALS	0.
S 35		INHAL	2.45E+03	ADRENALS	SI+CONT	S WALL	ULI WALL	LLI WALL	1.66E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	8.75E-06	NONE	NONE	NONE	NONE	ADRENALS	0.
CL 36	W	INHAL	2.17E+04	ULI WALL	SI+CONT	BLAD WAL	ADRENALS	S WALL	1.84E+03
		EXTGRD	7.43E-01	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	1.51E-07
		EXTCLD	4.57E-04	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	4.78E-11
AR 37		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	7.93E-04	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	2.54E-05
		EXTCLD	2.37E-07	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	7.62E-09
AR 41		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	3.45E+01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	3.61E+01
		EXTCLD	2.12E-01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	2.30E-01
K 40	D	INHAL	1.23E+04	S WALL	LLI WALL	SI+CONT	THYMUS	ADRENALS	1.12E+04
		EXTGRD	1.76E+01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	1.36E+01
		EXTCLD	2.68E-02	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	2.80E-02
K 42	D	INHAL	1.35E+03	LIVER	PANCREAS	THYMUS	ADRENALS	S WALL	3.84E+02
		EXTGRD	2.95E+01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	1.92E+01
		EXTCLD	4.96E-02	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	4.96E-02
CA 45	W	INHAL	6.55E+03	ADRENALS	S WALL	SI+CONT	ULI WALL	LLI WALL	1.64E+02
		EXTGRD	2.12E-08	SPLEEN	LLI WALL	PANCREAS	MARROW	ADRENALS	1.82E-09
		EXTCLD	4.69E-05	SPLEEN	LLI WALL	PANCREAS	MARROW	ADRENALS	2.41E-13
CA 47	W	INHAL	6.48E+03	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	5.38E+02
		EXTGRD	8.82E+01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	9.36E+01
		EXTCLD	1.75E-01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	1.90E-01
SC 46	Y	INHAL	2.93E+04	PANCREAS	LIVER	SPLEEN	LLI WALL	THYMUS	7.39E+03
		EXTGRD	1.77E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.94E+02
		EXTCLD	3.34E-01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	3.68E-01
SC 47	Y	INHAL	1.82E+03	SPLEEN	S WALL	SI+CONT	ULI WALL	LLI WALL	1.70E+01
		EXTGRD	1.11E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.21E+01
		EXTCLD	1.83E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.98E-02
TI 44	Y	INHAL	1.01E+06	SPLEEN	LIVER	ADRENALS	PANCREAS	THYMUS	1.35E+05
		EXTGRD	2.13E+02	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	2.24E+02
		EXTCLD	3.70E-01	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	4.02E-01
V 48	W	INHAL	1.01E+04	S WALL	SI+CONT	THYMUS	ULI WALL	LLI WALL	2.02E+03
		EXTGRD	2.51E+02	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	2.74E+02
		EXTCLD	4.81E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	5.24E-01
CR 51	Y	INHAL	3.31E+02	ADRENALS	PANCREAS	THYMUS	ULI WALL	LLI WALL	3.95E+01
		EXTGRD	3.10E+00	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	3.30E+00
		EXTCLD	5.02E-03	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	5.36E-03

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
MN 54	W	INHAL	6.65E+03	LLI WALL	PANCREAS	ADRENALS	THYMUS	LIVER	2.71E+03
		EXTGRD	7.68E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	8.43E+01
		EXTCLD	1.39E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.52E-01
MN 56	D	INHAL	3.73E+02	LIVER	LLI WALL	S WALL	SI+CONT	ULI WALL	4.39E+01
		EXTGRD	6.38E+01	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	6.49E+01
		EXTCLD	2.98E-01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	3.18E-01
FE 55	D	INHAL	2.67E+03	ULI WALL	ADRENALS	LLI WALL	LIVER	SPLEEN	1.98E+03
		EXTGRD	2.23E-02	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	7.17E-04
		EXTCLD	4.03E-06	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	1.30E-07
FE 59	D	INHAL	1.47E+04	ULI WALL	ADRENALS	LLI WALL	LIVER	SPLEEN	1.08E+04
		EXTGRD	1.00E+02	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	1.10E+02
		EXTCLD	1.96E-01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	2.15E-01
CO 57	Y	INHAL	8.99E+03	LLI WALL	LIVER	PANCREAS	ADRENALS	THYMUS	9.92E+02
		EXTGRD	1.31E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.44E+01
		EXTCLD	2.02E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.25E-02
CO 58	Y	INHAL	1.08E+04	ADRENALS	LIVER	PANCREAS	LLI WALL	THYMUS	3.19E+03
		EXTGRD	9.00E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	9.82E+01
		EXTCLD	1.61E-01	ADRENALS	ULI WALL	THYMUS	BRAIN	MARROW	1.75E-01
CO 60	Y	INHAL	2.17E+05	S WALL	ADRENALS	PANCREAS	LIVER	THYMUS	5.93E+04
		EXTGRD	2.08E+02	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	2.27E+02
		EXTCLD	4.12E-01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	4.50E-01
NI 59		INHAL	2.70E+03	ULI WALL	PANCREAS	UTERUS	ADRENALS	SPLEEN	2.85E+03
		EXTGRD	4.20E-02	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	1.35E-03
		EXTCLD	6.76E-06	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	2.17E-07
NI 63		INHAL	6.30E+03	ULI WALL	SI+CONT	BRAIN	BLAD WAL	ADRENALS	6.22E+03
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
CU 64	Y	INHAL	2.74E+02	PANCREAS	S WALL	SI+CONT	ULI WALL	LLI WALL	1.82E+01
		EXTGRD	1.45E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.54E+01
		EXTCLD	3.04E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.22E-02
CU 67	Y	INHAL	1.22E+03	PANCREAS	S WALL	SI+CONT	ULI WALL	LLI WALL	9.52E+01
		EXTGRD	1.20E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.31E+01
		EXTCLD	1.90E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.06E-02
ZN 65	Y	INHAL	2.02E+04	SPLEEN	PANCREAS	LIVER	ADRENALS	THYMUS	1.11E+04
		EXTGRD	5.00E+01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	5.50E+01
		EXTCLD	9.61E-02	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	1.06E-01
GA 67	W	INHAL	5.52E+02	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	3.45E+01
		EXTGRD	1.44E+01	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	1.56E+01
		EXTCLD	2.34E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.55E 02
GA 70	D	INHAL	3.12E+01	SPLEEN	LLI WALL	ULI WALL	SI+CONT	S WALL	1.37E+00
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
GA 72	W	INHAL	1.84E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	1.46E+02
		EXTGRD	1.96E+02	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	2.06E+02
		EXTCLD	4.81E-01	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	5.13E-01
GE 68	W	INHAL	5.14E+04	LIVER	ADRENALS	PANCREAS	S WALL	THYMUS	2.53E+03
		EXTGRD	9.85E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	9.53E+01
		EXTCLD	1.53E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.62E-01
GE 77	W	INHAL	1.04E+03	ADRENALS	PANCREAS	THYMUS	KIDNEYS	S WALL	1.16E+02
		EXTGRD	8.38E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	8.43E+01
		EXTCLD	1.76E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.88E-01
AS 72	W	INHAL	4.04E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	3.24E+02
		EXTGRD	1.59E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.60E+02
		EXTCLD	2.95E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	3.16E-01
AS 73	W	INHAL	3.42E+03	SPLEEN	LIVER	KIDNEYS	ULI WALL	LLI WALL	1.00E+02
		EXTGRD	9.18E-01	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	6.99E-01
		EXTCLD	7.31E-04	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	7.93E-04
AS 74	W	INHAL	7.86E+03	SPLEEN	KIDNEYS	LIVER	ULI WALL	LLI WALL	9.33E+02
		EXTGRD	7.39E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	7.68E+01
		EXTCLD	1.24E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.32E-01
AS 76	W	INHAL	3.70E+03	KIDNEYS	S WALL	SI+CONT	ULI WALL	LLI WALL	1.76E+02
		EXTGRD	4.59E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	3.79E+01
		EXTCLD	7.29E-02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	7.57E-02
AS 77	W	INHAL	1.04E+03	KIDNEYS	S WALL	SI+CONT	ULI WALL	LLI WALL	4.06E+01
		EXTGRD	1.32E+00	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	8.51E-01
		EXTCLD	1.79E-03	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	1.48E-03

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
SE 75	W	INHAL	8.39E+03	ADRENALS	SPLEEN	PANCREAS	LIVER	KIDNEYS	3.07E+03
		EXTGRD	3.94E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	4.23E+01
		EXTCLD	6.27E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	6.79E-02
SE 79	W	INHAL	9.74E+03	LLI WALL	PANCREAS	SPLEEN	LIVER	KIDNEYS	2.19E+03
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	9.25E-06	NONE	NONE	NONE	NONE	ADRENALS	0.
BR 76	W	INHAL	1.58E+03	LIVER	ADRENALS	PANCREAS	THYMUS	S WALL	4.10E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
BR 77	W	INHAL	2.74E+02	SPLEEN	PANCREAS	ADRENALS	S WALL	THYMUS	1.39E+02
		EXTGRD	2.89E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.09E+01
		EXTCLD	5.07E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	5.45E-02
BR 82	W	INHAL	1.52E+03	LIVER	PANCREAS	ADRENALS	THYMUS	S WALL	7.54E+02
		EXTGRD	2.20E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.39E+02
		EXTCLD	4.35E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	4.73E-01
KR 83M		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	3.53E-02	S WALL	LLI WALL	PANCREAS	MARROW	ADRENALS	3.69E-03
		EXTCLD	1.60E-05	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	2.34E-06
KR 85		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	1.06E+00	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	2.25E-01
		EXTCLD	8.33E-04	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.79E-04
KR 85M		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	1.01E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.03E+01
		EXTCLD	2.64E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.83E-02
KR 87		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	1.83E+01	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	1.62E+01
		EXTCLD	1.45E-01	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	1.50E-01
KR 88		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	1.03E+02	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	9.96E+01
		EXTCLD	4.80E-01	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	5.00E-01
KR 89		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	3.32E+00	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	3.32E+00
		EXTCLD	6.90E-01	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	7.32E-01
RB 84	D	INHAL	6.49E+03	ULI WALL	SI+CONT	LLI WALL	UTERUS	ADRENALS	5.27E+03
		EXTGRD	8.40E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	8.94E+01
		EXTCLD	1.48E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.61E-01
RB 86	D	INHAL	6.60E+03	SI+CONT	BLAD WAL	ADRENALS	UTERUS	S WALL	4.87E+03
		EXTGRD	1.62E+01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	8.98E+00
		EXTCLD	1.73E-02	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	1.73E-02
SR 85	Y	INHAL	4.99E+03	LIVER	ADRENALS	PANCREAS	LLI WALL	THYMUS	1.41E+03
		EXTGRD	4.84E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	5.12E+01
		EXTCLD	8.14E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	8.69E-02
SR 89	Y	INHAL	4.11E+04	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	2.91E+01
		EXTGRD	7.10E+00	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.36E-02
		EXTCLD	1.38E-03	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.51E-05
SR 90	Y	INHAL	1.29E+06	ADRENALS	S WALL	SI+CONT	ULI WALL	LLI WALL	9.85E+02
		EXTGRD	1.45E-01	ADRENALS	S WALL	SI+CONT	ULI WALL	ADRENALS	0.
		EXTCLD	3.35E-04	ADRENALS	S WALL	SI+CONT	ULI WALL	ADRENALS	0.
Y 90	Y	INHAL	8.35E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	1.89E+00
		EXTGRD	1.07E+01	LIVER	S WALL	SI+CONT	ULI WALL	ADRENALS	0.
		EXTCLD	2.30E-03	LIVER	S WALL	SI+CONT	ULI WALL	ADRENALS	0.
Y 91	Y	INHAL	4.82E+04	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	3.11E+01
		EXTGRD	7.68E+00	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	3.31E-01
		EXTCLD	2.00E-03	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	6.52E-04
ZR 93	D	INHAL	3.17E+05	PANCREAS	SPLEEN	ADRENALS	ULI WALL	LLI WALL	6.37E+01
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
ZR 95	D	INHAL	2.35E+04	PANCREAS	ULI WALL	KIDNEYS	LLI WALL	ADRENALS	5.27E+03
		EXTGRD	6.81E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	7.45E+01
		EXTCLD	1.21E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.32E-01
NB 94	Y	INHAL	4.09E+05	SPLEEN	LIVER	ADRENALS	PANCREAS	THYMUS	8.13E+04
		EXTGRD	1.45E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.59E+02
		EXTCLD	2.60E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.85E-01
NB 95	Y	INHAL	5.74E+03	ADRENALS	PANCREAS	ULI WALL	THYMUS	LLI WALL	1.31E+03
		EXTGRD	7.06E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	7.74E+01
		EXTCLD	1.26E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.38E-01

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
MO 99	Y	INHAL	3.93E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	5.56E+01
		EXTGRD	1.76E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.53E+01
		EXTCLD	2.62E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	2.77E-02
TC 99	W	INHAL	8.22E+03	LIVER	SI+CONT	ULI WALL	LLI WALL	S WALL	3.92E+03
		EXTGRD	5.71E-05	KIDNEYS	ULI WALL	BRAIN	THYMUS	MARROW	6.53E-05
		EXTCLD	6.30E-05	ULI WALL	KIDNEYS	BRAIN	THYMUS	MARROW	9.62E-08
TC 99M	D	INHAL	3.22E+01	SI+CONT	PANCREAS	LLI WALL	ULI WALL	S WALL	1.83E+02
		EXTGRD	8.80E+00	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	9.69E+00
		EXTCLD	2.11E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.32E-02
RU103	Y	INHAL	8.87E+03	ADRENALS	PANCREAS	THYMUS	ULI WALL	LLI WALL	9.41E+02
		EXTGRD	4.56E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	4.86E+01
		EXTCLD	7.70E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	8.21E-02
RU105	Y	INHAL	4.51E+02	PANCREAS	S WALL	SI+CONT	ULI WALL	LLI WALL	1.52E+01
		EXTGRD	4.61E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	4.75E+01
		EXTCLD	1.33E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.44E-01
RU106	Y	INHAL	4.73E+05	S WALL	THYMUS	SI+CONT	ULI WALL	LLI WALL	6.30E+03
		EXTGRD	3.38E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	2.07E+01
		EXTCLD	3.70E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.61E-02
RH106		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	5.07E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.10E-02
		EXTCLD	3.70E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.61E-02
PD107	Y	INHAL	1.26E+04	SI+CONT	LIVER	KIDNEYS	ULI WALL	LLI WALL	3.84E-01
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
PD109	Y	INHAL	1.08E+03	KIDNEYS	S WALL	SI+CONT	ULI WALL	LLI WALL	5.67E-01
		EXTGRD	3.14E+00	ADRENALS	ULI WALL	THYMUS	KIDNEYS	MARROW	6.36E-01
		EXTCLD	1.58E-03	ADRENALS	ULI WALL	KIDNEYS	THYMUS	MARROW	8.44E-04
AG110M	Y	INHAL	7.97E+04	SPLEEN	ADRENALS	PANCREAS	LIVER	THYMUS	2.34E+04
		EXTGRD	2.45E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.67E+02
		EXTCLD	4.52E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	4.93E-01
AG111	Y	INHAL	6.07E+03	S WALL	SI+CONT	LIVER	ULI WALL	LLI WALL	2.27E+01
		EXTGRD	3.35E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	3.30E+01
		EXTCLD	5.02E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	5.31E-02
CD109	D	INHAL	1.13E+05	PANCREAS	SPLEEN	ADRENALS	LIVER	KIDNEYS	9.74E+03
		EXTGRD	1.71E+00	THYMUS	ADRENALS	ULI WALL	KIDNEYS	MARROW	1.26E+00
		EXTCLD	1.08E-03	ADRENALS	ULI WALL	THYMUS	KIDNEYS	MARROW	9.55E-04
CD113M	D	INHAL	1.51E+06	SI+CONT	ULI WALL	LLI WALL	LIVER	KIDNEYS	1.22E+05
		EXTGRD	1.56E-01	SI+CONT	ULI WALL	LLI WALL	LIVER	ADRENALS	0.
		EXTCLD	2.97E-04	SI+CONT	ULI WALL	LLI WALL	LIVER	ADRENALS	0.
CD115	W	INHAL	4.16E+03	LIVER	SI+CONT	KIDNEYS	ULI WALL	LLI WALL	1.04E+02
		EXTGRD	2.04E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	1.95E+01
		EXTCLD	3.31E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.47E-02
IN111	W	INHAL	8.31E+02	LIVER	KIDNEYS	SI+CONT	ULI WALL	LLI WALL	6.99E+01
		EXTGRD	6.63E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	7.11E+01
		EXTCLD	1.09E-01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.17E-01
IN113M	D	INHAL	4.07E+01	KIDNEYS	LLI WALL	ULI WALL	SI+CONT	S WALL	4.36E+00
		EXTGRD	7.18E+00	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	7.62E+00
		EXTCLD	4.08E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	4.32E-02
IN114M	D	INHAL	8.80E+04	ULI WALL	LLI WALL	SPLEEN	LIVER	KIDNEYS	1.02E+04
		EXTGRD	2.13E+01	KIDNEYS	ADRENALS	BRAIN	THYMUS	MARROW	1.27E+01
		EXTCLD	2.17E-02	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	2.13E-02
SN113	W	INHAL	1.06E+04	PANCREAS	SI+CONT	THYMUS	ULI WALL	LLI WALL	8.31E+02
		EXTGRD	2.63E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	2.76E+01
		EXTCLD	4.21E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	4.44E-02
SN119M	W	INHAL	6.18E+03	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	1.99E+02
		EXTGRD	5.57E-01	THYMUS	BLAD WAL	ULI WALL	MARROW	KIDNEYS	4.17E-01
		EXTCLD	3.53E-04	THYMUS	BLAD WAL	ULI WALL	MARROW	KIDNEYS	2.68E-04
SN121	W	INHAL	5.03E+02	ADRENALS	S WALL	SI+CONT	ULI WALL	LLI WALL	3.10E+00
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
SN121M	W	INHAL	1.14E+04	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	6.84E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
SN123	W	INHAL	3.22E+04	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	6.62E+02
		EXTGRD	6.85E+00	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	6.56E-01
		EXTCLD	2.36E-03	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	1.26E-03

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
SN126	D	INHAL	8.67E+04	SI+CONT	ULI WALL	BRAIN	ADRENALS	LLI WALL	4.79E+04
		EXTGRD	1.60E+02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	1.66E+02
		EXTCLD	2.65E-01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	2.86E-01
SB122	W	INHAL	5.10E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	1.33E+02
		EXTGRD	4.60E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	4.28E+01
		EXTCLD	7.26E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	7.68E-02
SB124	W	INHAL	2.49E+04	SI+CONT	LIVER	THYMUS	ULI WALL	LLI WALL	2.47E+03
		EXTGRD	1.64E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.73E+02
		EXTCLD	3.17E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	3.40E-01
SB125	W	INHAL	1.21E+04	PANCREAS	LIVER	THYMUS	ULI WALL	LLI WALL	1.19E+03
		EXTGRD	4.05E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	4.33E+01
		EXTCLD	6.79E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	7.28E-02
SB126	W	INHAL	1.16E+04	LIVER	THYMUS	SI+CONT	ULI WALL	LLI WALL	1.76E+03
		EXTGRD	2.57E+02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	2.76E+02
		EXTCLD	4.50E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	4.88E-01
SB126M	D	INHAL	3.36E+01	SPLEEN	ULI WALL	PANCREAS	SI+CONT	S WALL	4.14E+00
		EXTGRD	8.83E+00	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	9.12E+00
		EXTCLD	2.57E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	2.77E-01
TE125M	D	INHAL	5.58E+03	ADRENALS	S WALL	SI+CONT	ULI WALL	LLI WALL	3.63E+02
		EXTGRD	1.94E+00	ULI WALL	BLAD WAL	THYMUS	MARROW	KIDNEYS	1.75E+00
		EXTCLD	1.58E-03	ULI WALL	BLAD WAL	THYMUS	MARROW	KIDNEYS	1.40E-03
TE127	W	INHAL	3.15E+02	PANCREAS	S WALL	SI+CONT	ULI WALL	LLI WALL	6.73E+00
		EXTGRD	7.63E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	3.77E-01
		EXTCLD	1.16E-03	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	8.21E-04
TE127M	W	INHAL	2.13E+04	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	3.54E+02
		EXTGRD	6.38E-01	ULI WALL	BLAD WAL	THYMUS	MARROW	KIDNEYS	5.56E-01
		EXTCLD	5.13E-04	ULI WALL	BLAD WAL	THYMUS	KIDNEYS	MARROW	4.52E-04
TE129	D	INHAL	8.87E+01	PANCREAS	LLI WALL	ULI WALL	SI+CONT	S WALL	5.97E+00
		EXTGRD	2.31E+00	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	1.15E+00
		EXTCLD	9.84E-03	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	9.25E-03
TE129M	W	INHAL	2.37E+04	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	5.71E+02
		EXTGRD	1.70E+01	ADRENALS	KIDNEYS	BRAIN	THYMUS	MARROW	9.07E+00
		EXTCLD	1.58E-02	ADRENALS	KIDNEYS	THYMUS	BRAIN	MARROW	1.52E-02
TE132	W	INHAL	9.35E+03	S WALL	ADRENALS	SI+CONT	ULI WALL	LLI WALL	2.30E+05
		EXTGRD	2.28E+02	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	2.43E+02
		EXTCLD	4.14E-01	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	4.49E-01
I 125	D	INHAL	2.39E+04	SPLEEN	LIVER	PANCREAS	S WALL	THYMUS	7.91E+05
		EXTGRD	2.28E+00	ULI WALL	BLAD WAL	THYMUS	MARROW	KIDNEYS	2.04E+00
		EXTCLD	1.79E-03	ULI WALL	BLAD WAL	THYMUS	MARROW	KIDNEYS	1.59E-03
I 126	D	INHAL	4.38E+04	SPLEEN	LIVER	ADRENALS	S WALL	THYMUS	1.44E+06
		EXTGPD	4.38E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	4.63E+01
		EXTCLD	7.42E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	7.98E-02
I 129	D	INHAL	1.72E+05	PANCREAS	SI+CONT	ULI WALL	S WALL	THYMUS	5.71E+06
		EXTGRD	2.03E+00	ULI WALL	BLAD WAL	THYMUS	KIDNEYS	MARROW	1.95E+00
		EXTCLD	1.34E-03	ULI WALL	BLAD WAL	THYMUS	KIDNEYS	MARROW	1.30E-03
I 131	D	INHAL	3.25E+04	LIVER	PANCREAS	ADRENALS	S WALL	THYMUS	1.07E+06
		EXTGRD	3.66E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	3.88E+01
		EXTCLD	6.10E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	6.50E-02
I 132	D	INHAL	3.76E+02	ADRENALS	SPLEEN	THYMUS	PANCREAS	S WALL	6.37E+03
		EXTGRD	8.08E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	8.58E+01
		EXTCLD	3.79E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	4.12E-01
I 133	D	INHAL	5.80E+03	SPLEEN	ADRENALS	PANCREAS	THYMUS	S WALL	1.78E+05
		EXTGRD	5.29E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	5.33E+01
		EXTCLD	9.85E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.05E-01
I 134	D	INHAL	1.30E+02	ADRENALS	SPLEEN	THYMUS	PANCREAS	S WALL	1.05E+03
		EXTGRD	3.83E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	4.07E+01
		EXTCLD	4.39E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	4.78E-01
I 135	D	INHAL	1.22E+03	SPLEEN	ADRENALS	PANCREAS	THYMUS	S WALL	3.10E+04
		EXTGRD	1.20E+02	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	1.26E+02
		EXTCLD	3.34E-01	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	3.61E-01
XE133		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	4.55E+00	ULI WALL	BLAD WAL	KIDNEYS	THYMUS	MARROW	5.02E+00
		EXTCLD	5.68E-03	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	6.29E-03
XE133M		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	3.61E+00	BLAD WAL	ADRENALS	THYMUS	KIDNEYS	MARROW	3.73E+00
		EXTCLD	5.02E-03	ULI WALL	ADRENALS	KIDNEYS	THYMUS	MARROW	4.99E-03

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
XE135		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	1.99E+01	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	1.99E+01
		EXTCLD	4.03E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	4.27E-02
XE135M		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	1.91E+00	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	2.00E+00
		EXTCLD	6.85E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	7.31E-02
XE137		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	3.88E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	2.12E-01
		EXTCLD	3.49E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	3.25E-02
XE138		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	1.33E+01	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	1.33E+01
		EXTCLD	6.08E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	6.45E-01
CS134	D	INHAL	4.62E+04	BLAD WAL	SI+CONT	LLI WALL	UTERUS	ADRENALS	4.06E+04
		EXTGRD	1.44E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.57E+02
		EXTCLD	2.55E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.77E-01
CS135	D	INHAL	4.53E+03	ULI WALL	SI+CONT	BLAD WAL	ADRENALS	S WALL	4.39E+03
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	1.81E-05	NONE	NONE	NONE	NONE	ADRENALS	0.
CS136	D	INHAL	7.30E+03	LLI WALL	SI+CONT	BLAD WAL	ADRENALS	UTERUS	6.33E+03
		EXTGRD	1.94E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.13E+02
		EXTCLD	3.58E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	3.92E-01
CS137	D	INHAL	3.18E+04	ULI WALL	UTERUS	SI+CONT	LLI WALL	ADRENALS	2.90E+04
		EXTGRD	5.69E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	6.07E+01
		EXTCLD	9.76E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.06E-01
BA131	D	INHAL	6.63E+02	UTERUS	S WALL	SI+CONT	ULI WALL	LLI WALL	1.69E+02
		EXTGRD	4.49E+01	ADRENALS	KIDNEYS	BRAIN	THYMUS	MARROW	4.79E+01
		EXTCLD	7.27E-02	KIDNEYS	ADRENALS	BRAIN	THYMUS	MARROW	7.80E-02
BA133	D	INHAL	7.76E+03	PANCREAS	ULI WALL	ADRENALS	LLI WALL	BRAIN	3.66E+03
		EXTGRD	3.83E+01	ADRENALS	BRAIN	KIDNEYS	THYMUS	MARROW	4.07E+01
		EXTCLD	5.84E-02	KIDNEYS	ADRENALS	BRAIN	THYMUS	MARROW	6.24E-02
BA137M		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	4.35E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	4.65E-01
		EXTCLD	9.73E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.06E-01
BA140	D	INHAL	3.70E+03	S WALL	ADRENALS	SI+CONT	ULI WALL	LLI WALL	9.37E+02
		EXTGRD	1.97E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	1.92E+01
		EXTCLD	3.04E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	3.20E-02
LA140	W	INHAL	4.79E+03	S WALL	LIVER	SI+CONT	ULI WALL	LLI WALL	2.51E+02
		EXTGRD	1.87E+02	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	1.96E+02
		EXTCLD	3.92E-01	KIDNEYS	ULI WALL	THYMUS	MARROW	BRAIN	4.20E-01
CE137	Y	INHAL	4.15E+01	PANCREAS	S WALL	SI+CONT	LLI WALL	ULI WALL	4.83E-01
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
CE139	Y	INHAL	8.96E+03	PANCREAS	SPLEEN	THYMUS	LIVER	LLI WALL	6.08E+02
		EXTGRD	1.61E+01	ULI WALL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.75E+01
		EXTCLD	2.38E-02	BRAIN	KIDNEYS	ADRENALS	THYMUS	MARROW	2.60E-02
CE141	Y	INHAL	8.86E+03	SPLEEN	LIVER	SI+CONT	ULI WALL	LLI WALL	9.33E+01
		EXTGRD	8.03E+00	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	8.80E+00
		EXTCLD	1.25E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.35E-02
CE143	Y	INHAL	3.35E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	2.28E+01
		EXTGRD	2.76E+01	ADRENALS	KIDNEYS	BRAIN	THYMUS	MARROW	2.59E+01
		EXTCLD	4.27E-02	KIDNEYS	ADRENALS	BRAIN	THYMUS	MARROW	4.51E-02
CE144	Y	INHAL	3.71E+05	SI+CONT	ULI WALL	SPLEEN	LIVER	LLI WALL	1.07E+03
		EXTGRD	2.90E+00	ULI WALL	BLAD WAL	KIDNEYS	THYMUS	MARROW	3.17E+00
		EXTCLD	3.80E-03	ULI WALL	BLAD WAL	KIDNEYS	THYMUS	MARROW	4.12E-03
PR143	Y	INHAL	8.01E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	6.15E-06
		EXTGRD	2.08E+00	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	8.96E-07
		EXTCLD	6.33E-04	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.60E-09
PR144	Y	INHAL	4.28E+01	THYMUS	LIVER	ULI WALL	SI+CONT	S WALL	3.10E-02
		EXTGRD	8.34E-01	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	1.51E-01
		EXTCLD	8.70E-03	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	6.04E-03
PR144M		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	3.67E-01	ULI WALL	BLAD WAL	THYMUS	KIDNEYS	MARROW	8.40E-02
		EXTCLD	9.53E-03	ULI WALL	BRAIN	KIDNEYS	THYMUS	MARROW	6.95E-03
ND147	Y	INHAL	6.76E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	6.66E+01
		EXTGRD	1.44E+01	ADRENALS	BRAIN	KIDNEYS	THYMUS	MARROW	1.46E+01
		EXTCLD	2.16E-02	ADRENALS	KIDNEYS	BRAIN	THYMUS	MARROW	2.30E-02

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
PM145	W	INHAL	2.51E+04	ULI WALL	KIDNEYS	PANCREAS	ADRENALS	LIVER	6.84E+02
		EXTGRD	2.67E+00	LIVER	BLAD WAL	THYMUS	KIDNEYS	MARROW	2.88E+00
		EXTCLD	2.67E-03	LIVER	BLAD WAL	THYMUS	KIDNEYS	MARROW	2.90E-03
PM147	W	INHAL	2.55E+04	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	4.83E-02
		EXTGRD	3.74E-04	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	4.17E-04
		EXTCLD	2.61E-05	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	6.47E-07
SM145	W	INHAL	1.09E+04	PANCREAS	ULI WALL	ADRENALS	LLI WALL	LIVER	2.73E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
SM151	W	INHAL	2.97E+04	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	4.83E-02
		EXTGRD	4.94E-04	LLI WALL	ULI WALL	ADRENALS	KIDNEYS	MARROW	2.38E-04
		EXTCLD	1.50E-07	LLI WALL	ULI WALL	ADRENALS	KIDNEYS	MARROW	7.75E-08
EU152	W	INHAL	2.19E+05	ULI WALL	KIDNEYS	PANCREAS	ADRENALS	LIVER	3.02E+04
		EXTGRD	1.02E+02	ULI WALL	KIDNEYS	BRAIN	THYMUS	MARROW	1.11E+02
		EXTCLD	1.88E-01	ULI WALL	KIDNEYS	THYMUS	BRAIN	MARROW	2.05E-01
EU154	W	INHAL	2.83E+05	ULI WALL	KIDNEYS	PANCREAS	ADRENALS	LIVER	2.61E+04
		EXTGRD	1.12E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.21E+02
		EXTCLD	2.07E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.26E-01
EU155	W	INHAL	4.11E+04	PANCREAS	ADRENALS	KIDNEYS	LLI WALL	LIVER	8.78E+02
		EXTGRD	6.52E+00	ULI WALL	BLAD WAL	KIDNEYS	THYMUS	MARROW	7.40E+00
		EXTCLD	9.10E-03	BRAIN	BLAD WAL	KIDNEYS	THYMUS	MARROW	1.03E-02
GD151	D	INHAL	8.78E+03	LLI WALL	PANCREAS	ADRENALS	KIDNEYS	LIVER	3.49E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
GD153	D	INHAL	2.36E+04	ULI WALL	PANCREAS	ADRENALS	KIDNEYS	LIVER	1.04E+03
		EXTGRD	1.16E+01	ULI WALL	BLAD WAL	KIDNEYS	THYMUS	MARROW	1.30E+01
		EXTCLD	1.42E-02	ULI WALL	BLAD WAL	KIDNEYS	THYMUS	MARROW	1.60E-02
TB160	W	INHAL	2.47E+04	ADRENALS	KIDNEYS	ULI WALL	LLI WALL	LIVER	2.39E+03
		EXTGRD	9.75E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.06E+02
		EXTCLD	1.79E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.96E-01
DY159	W	INHAL	2.40E+03	THYMUS	ADRENALS	ULI WALL	LLI WALL	LIVER	1.14E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
DY165	W	INHAL	1.33E+02	KIDNEYS	LLI WALL	S WALL	SI+CONT	ULI WALL	1.99E-01
		EXTGRD	2.69E+00	ADRENALS	BRAIN	KIDNEYS	THYMUS	MARROW	1.05E+00
		EXTCLD	4.89E-03	ADRENALS	KIDNEYS	BRAIN	THYMUS	MARROW	4.30E-03
HO166M	W	INHAL	7.67E+05	S WALL	KIDNEYS	ADRENALS	LIVER	PANCREAS	7.83E+04
		EXTGRD	1.51E+02	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	1.64E+02
		EXTCLD	2.61E-01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	2.84E-01
ER169	W	INHAL	2.06E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	1.03E+01
		EXTGRD	4.76E-04	ULI WALL	BRAIN	THYMUS	ADRENALS	MARROW	2.01E-04
		EXTCLD	9.38E-05	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.97E-07
TM170	W	INHAL	2.60E+04	S WALL	SI+CONT	LIVER	ULI WALL	LLI WALL	5.20E+02
		EXTGRD	2.69E+00	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	6.53E-01
		EXTCLD	1.37E-03	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	8.49E-04
YB169	Y	INHAL	7.97E+03	S WALL	SI+CONT	THYMUS	ULI WALL	LLI WALL	3.14E+02
		EXTGRD	3.24E+01	ADRENALS	BLAD WAL	KIDNEYS	THYMUS	MARROW	3.62E+01
		EXTCLD	4.55E-02	BRAIN	ADRENALS	KIDNEYS	THYMUS	MARROW	5.06E-02
YB177	Y	INHAL	1.44E+02	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	1.44E+00
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
LU172	Y	INHAL	4.94E+03	S WALL	THYMUS	SI+CONT	ULI WALL	LLI WALL	6.44E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
LU177	Y	INHAL	2.43E+03	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	9.04E+00
		EXTGRD	3.57E+00	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	3.90E+00
		EXTCLD	5.75E-03	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	6.10E-03
HF172	D	INHAL	3.15E+05	PANCREAS	KIDNEYS	LLI WALL	ADRENALS	BRAIN	5.27E+04
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
HF181	D	INHAL	1.53E+04	SI+CONT	ADRENALS	BRAIN	ULI WALL	LLI WALL	2.14E+03
		EXTGRD	5.26E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	5.65E+01
		EXTCLD	8.66E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	9.28E-02
TA182	Y	INHAL	4.42E+04	PANCREAS	LIVER	ULI WALL	THYMUS	LLI WALL	5.60E+03
		EXTGRD	1.12E+02	ULI WALL	KIDNEYS	BRAIN	THYMUS	MARROW	1.23E+02
		EXTCLD	2.13E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.33E-01

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
TA183	Y	INHAL	5.16E+03	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	6.48E+01
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
W 181	D	INHAL	1.50E+02	LIVER	ULI WALL	LLI WALL	SPLEEN	KIDNEYS	9.92E+00
		EXTGRD	4.27E+00	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	4.90E+00
		EXTCLD	5.24E-03	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	6.04E-03
W 185	D	INHAL	7.42E+02	LIVER	ULI WALL	SPLEEN	KIDNEYS	LLI WALL	1.04E-02
		EXTGRD	3.91E-03	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	3.16E-03
		EXTCLD	1.60E-04	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	4.93E-06
W 187	D	INHAL	6.12E+02	SPLEEN	KIDNEYS	SI+CONT	ULI WALL	LLI WALL	1.60E+01
		EXTGRD	4.16E+01	KIDNEYS	ADRENALS	BRAIN	THYMUS	MARROW	4.37E+01
		EXTCLD	7.72E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	8.33E-02
RE188	W	INHAL	1.99E+03	LIVER	SI+CONT	ULI WALL	LLI WALL	S WALL	8.02E+03
		EXTGRD	1.28E+01	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	5.29E+00
		EXTCLD	1.13E-02	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	1.04E-02
OS191	Y	INHAL	4.12E+03	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	5.23E+01
		EXTGRD	7.71E+00	BLAD WAL	BRAIN	KIDNEYS	THYMUS	MARROW	8.67E+00
		EXTCLD	1.10E-02	BLAD WAL	BRAIN	KIDNEYS	THYMUS	MARROW	1.25E-02
IR192	Y	INHAL	2.79E+04	PANCREAS	LIVER	THYMUS	ULI WALL	LLI WALL	2.38E+03
		EXTGRD	7.95E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	8.49E+01
		EXTCLD	1.31E-01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	1.39E-01
IR194	Y	INHAL	2.87E+03	KIDNEYS	S WALL	SI+CONT	ULI WALL	LLI WALL	7.47E+00
		EXTGRD	1.58E+01	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	8.02E+00
		EXTCLD	1.66E-02	ULI WALL	ADRENALS	THYMUS	BRAIN	MARROW	1.59E-02
PT193	D	INHAL	2.25E+02	LLI WALL	LIVER	SPLEEN	ADRENALS	KIDNEYS	5.20E+01
		EXTGRD	5.63E-02	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	1.81E-03
		EXTCLD	7.73E-06	SPLEEN	LLI WALL	MARROW	PANCREAS	ADRENALS	2.48E-07
PT197	D	INHAL	5.59E+02	ADRENALS	SI+CONT	KIDNEYS	ULI WALL	LLI WALL	5.16E+01
		EXTGRD	2.44E+00	BLAD WAL	BRAIN	KIDNEYS	THYMUS	MARROW	2.41E+00
		EXTCLD	3.95E-03	ADRENALS	KIDNEYS	BRAIN	THYMUS	MARROW	4.08E-03
AU198	Y	INHAL	3.25E+03	BLAD WAL	S WALL	SI+CONT	ULI WALL	LLI WALL	8.67E+01
		EXTGRD	3.94E+01	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	3.99E+01
		EXTCLD	6.50E-02	KIDNEYS	ADRENALS	THYMUS	BRAIN	MARROW	6.86E-02
AU199	Y	INHAL	1.48E+03	BLAD WAL	S WALL	SI+CONT	ULI WALL	LLI WALL	2.37E+01
		EXTGRD	8.98E+00	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	9.87E+00
		EXTCLD	1.45E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.59E-02
HG203		INHAL	7.27E+03	SPLEEN	PANCREAS	ADRENALS	BRAIN	KIDNEYS	2.96E+03
		EXTGRD	2.28E+01	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	2.44E+01
		EXTCLD	3.66E-02	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	3.92E-02
TL201	D	INHAL	2.33E+02	SPLEEN	THYMUS	PANCREAS	S WALL	KIDNEYS	1.15E+02
		EXTGRD	9.45E+00	BLAD WAL	BRAIN	KIDNEYS	THYMUS	MARROW	1.07E+01
		EXTCLD	1.39E-02	BLAD WAL	BRAIN	KIDNEYS	THYMUS	MARROW	1.58E-02
TL204	D	INHAL	2.39E+03	BRAIN	BLAD WAL	ADRENALS	S WALL	KIDNEYS	1.52E+03
		EXTGRD	1.30E+00	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	1.35E-01
		EXTCLD	6.57E-04	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	1.88E-04
TL208		INHAL	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTGRD	2.60E+00	ULI WALL	KIDNEYS	THYMUS	MARROW	BRAIN	2.66E+00
		EXTCLD	6.29E-01	ULI WALL	THYMUS	KIDNEYS	MARROW	BRAIN	6.55E-01
PB210	D	INHAL	1.35E+07	SI+CONT	BLAD WAL	ADRENALS	KIDNEYS	LIVER	1.16E+06
		EXTGRD	2.82E-01	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	2.18E-01
		EXTCLD	2.14E-04	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	2.29E-04
BI207	W	INHAL	1.98E+04	PANCREAS	ULI WALL	KIDNEYS	THYMUS	LLI WALL	3.95E+03
		EXTGRD	1.40E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.51E+02
		EXTCLD	2.53E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	2.76E-01
BI210	W	INHAL	1.93E+05	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	2.37E+02
		EXTGRD	3.49E+00	S WALL	SI+CONT	ULI WALL	LLI WALL	ADRENALS	0.
		EXTCLD	8.28E-04	S WALL	SI+CONT	ULI WALL	LLI WALL	ADRENALS	0.
PO210	W	INHAL	8.51E+06	ULI WALL	LLI WALL	LIVER	KIDNEYS	SPLEEN	4.61E+05
		EXTGRD	7.85E-04	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	8.59E-04
		EXTCLD	1.41E-06	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.54E-06
RA226	W	INHAL	8.48E+06	BLAD WAL	ADRENALS	SI+CONT	ULI WALL	LLI WALL	3.73E+05
		EXTGRD	6.93E-01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	7.53E-01
		EXTCLD	1.09E-03	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.18E-03
AC227	D	INHAL	6.63E+09	ULI WALL	KIDNEYS	PANCREAS	ADRENALS	LIVER	1.31E+05
		EXTGRD	1.99E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.46E-02
		EXTCLD	2.00E-05	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.13E-05

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
AC228	D	INHAL	3.05E+05	S WALL	SI+CONT	LLI WALL	ULI WALL	LIVER	3.22E+01
		EXTGRD	5.69E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	5.97E+01
		EXTCLD	1.54E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.68E-01
TH227	Y	INHAL	1.60E+07	S WALL	SI+CONT	ULI WALL	LIVER	LLI WALL	1.08E+04
		EXTGRD	1.07E+01	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	1.14E+01
		EXTCLD	1.66E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.80E-02
TH228	W	INHAL	2.47E+08	SI+CONT	ADRENALS	ULI WALL	LLI WALL	LIVER	4.90E+06
		EXTGRD	2.57E-01	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	2.33E-01
		EXTCLD	3.15E-04	KIDNEYS	ADRENALS	BRAIN	THYMUS	MARROW	3.46E-04
TH230	W	INHAL	3.22E+08	ADRENALS	SI+CONT	ULI WALL	LLI WALL	LIVER	1.49E+06
		EXTGRD	8.63E-02	BRAIN	KIDNEYS	ADRENALS	THYMUS	MARROW	4.93E-02
		EXTCLD	6.27E-05	BLAD WAL	BRAIN	KIDNEYS	THYMUS	MARROW	6.50E-05
TH232	W	INHAL	1.62E+09	KIDNEYS	PANCREAS	LLI WALL	ADRENALS	LIVER	2.72E+06
		EXTGRD	7.11E-02	S WALL	KIDNEYS	THYMUS	ADRENALS	MARROW	2.72E-02
		EXTCLD	3.02E-05	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	2.80E-05
TH234	Y	INHAL	3.46E+04	LIVER	S WALL	SI+CONT	ULI WALL	LLI WALL	4.65E+01
		EXTGRD	1.19E+01	ULI WALL	KIDNEYS	BRAIN	THYMUS	MARROW	2.12E+00
		EXTCLD	5.13E-03	ULI WALL	KIDNEYS	BRAIN	THYMUS	MARROW	3.49E-03
PA231	W	INHAL	1.27E+09	ULI WALL	BRAIN	LLI WALL	LIVER	KIDNEYS	2.80E+04
		EXTGRD	3.29E+00	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	3.26E+00
		EXTCLD	4.80E-03	KIDNEYS	BRAIN	ADRENALS	THYMUS	MARROW	5.09E-03
PA233	Y	INHAL	9.44E+03	THYMUS	S WALL	SI+CONT	ULI WALL	LLI WALL	2.06E+02
		EXTGRD	2.15E+01	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	2.29E+01
		EXTCLD	3.41E-02	ULI WALL	ADRENALS	BRAIN	THYMUS	MARROW	3.65E-02
PA234	Y	INHAL	8.05E+02	PANCREAS	S WALL	SI+CONT	LLI WALL	ULI WALL	4.50E+01
		EXTGRD	1.23E+02	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.33E+02
		EXTCLD	3.24E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	3.54E-01
U 232D	D	INHAL	1.26E+07	PANCREAS	ULI WALL	ADRENALS	LLI WALL	KIDNEYS	2.67E+05
		EXTGRD	9.78E-02	S WALL	LLI WALL	THYMUS	ADRENALS	MARROW	3.50E-02
		EXTCLD	4.26E-05	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	3.83E-05
U 232W	W	INHAL	1.47E+07	ADRENALS	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	9.04E+04
		EXTGRD	3.11E-01	S WALL	LLI WALL	THYMUS	ADRENALS	MARROW	3.50E-02
		EXTCLD	3.97E-04	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	3.83E-05
U 232Y	Y	INHAL	6.52E+08	LIVER	PANCREAS	THYMUS	LLI WALL	KIDNEYS	8.89E+04
		EXTGRD	9.85E-02	S WALL	LLI WALL	THYMUS	ADRENALS	MARROW	3.50E-02
		EXTCLD	4.27E-05	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	3.83E-05
U 233D	D	INHAL	2.76E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	9.30E+04
		EXTGRD	6.82E-02	ULI WALL	BRAIN	THYMUS	ADRENALS	MARROW	2.80E-02
		EXTCLD	4.39E-05	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	3.93E-05
U 233W	W	INHAL	7.91E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	2.79E+04
		EXTGRD	7.37E+00	ULI WALL	BRAIN	THYMUS	ADRENALS	MARROW	2.80E-02
		EXTCLD	2.28E-03	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	3.93E-05
U 233Y	Y	INHAL	1.34E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	9.88E+03
		EXTGRD	3.88E+00	ULI WALL	BRAIN	THYMUS	ADRENALS	MARROW	2.80E-02
		EXTCLD	9.84E-04	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	3.93E-05
U 234D	D	INHAL	2.70E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	9.15E+04
		EXTGRD	1.41E-01	S WALL	THYMUS	LLI WALL	ADRENALS	MARROW	2.08E-02
		EXTCLD	7.63E-05	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.90E-05
U 234W	W	INHAL	7.81E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	2.75E+04
		EXTGRD	1.84E-01	S WALL	THYMUS	LLI WALL	ADRENALS	MARROW	2.08E-02
		EXTCLD	2.36E-04	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.90E-05
U 234Y	Y	INHAL	1.31E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	9.70E+03
		EXTGRD	3.14E-01	S WALL	THYMUS	LLI WALL	ADRENALS	MARROW	2.08E-02
		EXTCLD	3.67E-04	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.90E-05
U 235D	D	INHAL	2.51E+06	SI+CONT	ADRENALS	ULI WALL	LLI WALL	KIDNEYS	8.67E+04
		EXTGRD	1.80E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.70E+01
		EXTCLD	2.72E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.67E-02
U 235W	W	INHAL	7.22E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	2.64E+04
		EXTGRD	1.58E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.70E+01
		EXTCLD	2.47E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.67E-02
U 235Y	Y	INHAL	1.21E+08	ADRENALS	THYMUS	ULI WALL	LLI WALL	KIDNEYS	1.50E+04
		EXTGRD	1.81E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.70E+01
		EXTCLD	2.58E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.67E-02
U 236D	D	INHAL	2.56E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	8.67E+04
		EXTGRD	1.57E-01	THYMUS	PANCREAS	LLI WALL	ADRENALS	MARROW	1.63E-02
		EXTCLD	1.15E-04	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.40E-05

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
U 236W	W	INHAL	7.37E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	2.61E+04
		EXTGRD	7.33E-02	THYMUS	PANCREAS	LLI WALL	ADRENALS	MARROW	1.63E-02
		EXTCLD	2.01E-05	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.40E-05
U 236Y	Y	INHAL	1.24E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	9.19E+03
		EXTGRD	7.37E+00	THYMUS	PANCREAS	LLI WALL	ADRENALS	MARROW	1.63E-02
		EXTCLD	2.11E-03	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.40E-05
U 238D	D	INHAL	2.42E+06	ADRENALS	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	8.13E+04
		EXTGRD	1.78E-01	S WALL	PANCREAS	LLI WALL	ADRENALS	MARROW	1.42E-02
		EXTCLD	3.03E-04	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.18E-05
U 238W	W	INHAL	6.94E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	2.46E+04
		EXTGRD	6.35E-02	S WALL	PANCREAS	LLI WALL	ADRENALS	MARROW	1.42E-02
		EXTCLD	1.70E-05	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.18E-05
U 238Y	Y	INHAL	1.17E+08	THYMUS	SI+CONT	ULI WALL	LLI WALL	KIDNEYS	9.99E+03
		EXTGRD	5.84E-02	S WALL	PANCREAS	LLI WALL	ADRENALS	MARROW	1.42E-02
		EXTCLD	1.63E-05	BLAD WAL	ADRENALS	KIDNEYS	THYMUS	MARROW	1.18E-05
NP237	W	INHAL	4.94E+08	KIDNEYS	LLI WALL	PANCREAS	ADRENALS	LIVER	3.77E+04
		EXTGRD	8.32E+00	ULI WALL	ADRENALS	KIDNEYS	THYMUS	MARROW	2.93E+00
		EXTCLD	6.71E-03	ADRENALS	BRAIN	KIDNEYS	THYMUS	MARROW	4.05E-03
NP239	W	INHAL	2.43E+03	S WALL	SI+CONT	LIVER	ULI WALL	LLI WALL	2.14E+01
		EXTGRD	1.66E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.79E+01
		EXTCLD	2.67E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.92E-02
PU236W	W	INHAL	1.63E+08	PANCREAS	ADRENALS	ULI WALL	LLI WALL	LIVER	3.99E+03
		EXTGRD	4.89E-01	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.81E-02
		EXTCLD	6.89E-04	S WALL	KIDNEYS	ADRENALS	THYMUS	MARROW	9.72E-06
PU236Y	Y	INHAL	1.35E+08	SI+CONT	ADRENALS	ULI WALL	LLI WALL	LIVER	2.49E+03
		EXTGRD	9.46E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.81E-02
		EXTCLD	1.95E-05	S WALL	KIDNEYS	ADRENALS	THYMUS	MARROW	9.72E-06
PU238W	W	INHAL	4.58E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	1.68E+01
		EXTGRD	7.73E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.36E-02
		EXTCLD	1.50E-05	S WALL	KIDNEYS	THYMUS	ADRENALS	MARROW	5.36E-06
PU238Y	Y	INHAL	3.11E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	7.28E+00
		EXTGRD	7.73E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.36E-02
		EXTCLD	1.38E-05	S WALL	KIDNEYS	THYMUS	ADRENALS	MARROW	5.36E-06
PU239W	W	INHAL	5.11E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	1.60E+01
		EXTGRD	3.12E+00	SPLEEN	PANCREAS	LLI WALL	ADRENALS	MARROW	1.05E-02
		EXTCLD	7.69E-04	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.06E-05
PU239Y	Y	INHAL	3.36E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	8.56E+00
		EXTGRD	2.66E+00	SPLEEN	PANCREAS	LLI WALL	ADRENALS	MARROW	1.05E-02
		EXTCLD	2.53E-03	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.06E-05
PU240W	W	INHAL	5.11E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	2.03E+01
		EXTGRD	5.04E-01	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.34E-02
		EXTCLD	7.10E-04	S WALL	KIDNEYS	THYMUS	ADRENALS	MARROW	5.57E-06
PU240Y	Y	INHAL	3.36E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	9.04E+00
		EXTGRD	7.86E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.34E-02
		EXTCLD	1.43E-05	S WALL	KIDNEYS	THYMUS	ADRENALS	MARROW	5.57E-06
PU241W	W	INHAL	1.03E+07	PANCREAS	ULI WALL	ADRENALS	LLI WALL	LIVER	5.45E+01
		EXTGRD	1.79E-01	PANCREAS	ULI WALL	ADRENALS	LLI WALL	ADRENALS	0.
		EXTCLD	3.79E-04	PANCREAS	ULI WALL	ADRENALS	LLI WALL	ADRENALS	0.
PU241Y	Y	INHAL	5.70E+06	PANCREAS	ADRENALS	ULI WALL	LLI WALL	LIVER	2.85E+01
		EXTGRD	4.50E-03	PANCREAS	ADRENALS	ULI WALL	LLI WALL	ADRENALS	0.
		EXTCLD	7.90E-07	PANCREAS	ADRENALS	ULI WALL	LLI WALL	ADRENALS	0.
PU242W	W	INHAL	4.86E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	1.08E+02
		EXTGRD	6.15E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.13E-02
		EXTCLD	6.51E-05	S WALL	KIDNEYS	ADRENALS	THYMUS	MARROW	4.95E-06
PU242Y	Y	INHAL	3.20E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	6.59E+01
		EXTGRD	6.57E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.13E-02
		EXTCLD	1.22E-05	S WALL	KIDNEYS	ADRENALS	THYMUS	MARROW	4.95E-06
AM241	W	INHAL	5.25E+08	PANCREAS	ADRENALS	ULI WALL	LLI WALL	LIVER	2.75E+03
		EXTGRD	2.69E+00	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	2.86E+00
		EXTCLD	2.98E-03	LIVER	BLAD WAL	KIDNEYS	THYMUS	MARROW	3.45E-03
AM242	W	INHAL	5.94E+04	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	6.04E-01
		EXTGRD	1.39E+00	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.39E+00
		EXTCLD	2.17E-03	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.44E-03
AM242M	W	INHAL	5.07E+08	PANCREAS	ULI WALL	ADRENALS	LLI WALL	LIVER	1.97E+03
		EXTGRD	2.50E-01	S WALL	PANCREAS	LLI WALL	ADRENALS	MARROW	7.40E-02
		EXTCLD	7.44E-05	S WALL	KIDNEYS	ADRENALS	THYMUS	MARROW	5.24E-05

Table A.1 (Continued)

Effective Dose Equivalent (EDE) and Thyroid Dose Factors, Clearance Class (CC), and Remainder Category Organs (INHAL=REM/CI INHALED, EXTGRD=REM*M**2/CI, EXTCLD=REM*M**3/CI)

NUCLIDE	CC	EXP.PTH	EDE	FIVE ORGANS ASSIGNED TO THE REMAINDER CATEGORY					THYROID
AM243	W	INHAL	5.24E+08	KIDNEYS	PANCREAS	LLI WALL	ADRENALS	LIVER	3.21E+04
		EXTGRD	5.95E+00	BRAIN	BLAD WAL	KIDNEYS	THYMUS	MARROW	6.70E+00
		EXTCLD	8.01E-03	BRAIN	BLAD WAL	KIDNEYS	THYMUS	MARROW	9.33E-03
CM242	W	INHAL	1.75E+07	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	4.68E-01
		EXTGRD	8.40E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.67E-02
		EXTCLD	1.54E-05	S WALL	LLI WALL	THYMUS	ADRENALS	MARROW	5.71E-06
CM243	W	INHAL	3.52E+08	PANCREAS	ADRENALS	ULI WALL	LLI WALL	LIVER	1.19E+04
		EXTGRD	1.32E+01	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.42E+01
		EXTCLD	2.00E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	2.22E-02
CM244	W	INHAL	2.79E+08	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	2.28E+01
		EXTGRD	7.48E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.43E-02
		EXTCLD	1.31E-05	S WALL	THYMUS	LLI WALL	ADRENALS	MARROW	4.34E-06
CM245	W	INHAL	5.41E+08	PANCREAS	ADRENALS	ULI WALL	LLI WALL	LIVER	1.19E+04
		EXTGRD	7.69E+00	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	8.30E+00
		EXTCLD	1.12E-02	ULI WALL	BRAIN	ADRENALS	THYMUS	MARROW	1.25E-02
CM246	W	INHAL	5.38E+08	KIDNEYS	ADRENALS	ULI WALL	LLI WALL	LIVER	5.71E+03
		EXTGRD	6.61E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.23E-02
		EXTCLD	1.10E-05	S WALL	PANCREAS	LLI WALL	ADRENALS	MARROW	3.06E-06
CM248	W	INHAL	1.97E+09	ULI WALL	PANCREAS	KIDNEYS	ADRENALS	LIVER	2.02E+06
		EXTGRD	5.30E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.05E-02
		EXTCLD	9.64E-06	S WALL	LLI WALL	THYMUS	ADRENALS	MARROW	3.55E-06
BK247	W	INHAL	5.53E+08	PANCREAS	ADRENALS	ULI WALL	LLI WALL	LIVER	1.18E+04
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
BK249	W	INHAL	1.34E+06	PANCREAS	ADRENALS	ULI WALL	LLI WALL	LIVER	1.35E+02
		EXTGRD	0.	NONE	NONE	NONE	NONE	NONE	0.
		EXTCLD	0.	NONE	NONE	NONE	NONE	NONE	0.
BK250	W	INHAL	6.89E+03	LLI WALL	S WALL	SI+CONT	ULI WALL	LIVER	1.15E+01
		EXTGRD	3.71E+01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	4.12E+01
		EXTCLD	1.46E-01	KIDNEYS	ULI WALL	THYMUS	BRAIN	MARROW	1.62E-01
CF252	W	INHAL	1.20E+08	LLI WALL	PANCREAS	KIDNEYS	ADRENALS	LIVER	9.11E+04
		EXTGRD	5.71E-02	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	1.35E-02
		EXTCLD	1.17E-05	S WALL	LLI WALL	THYMUS	ADRENALS	MARROW	5.01E-06
CF253	Y	INHAL	3.07E+06	S WALL	SI+CONT	ULI WALL	LLI WALL	LIVER	4.65E+00
		EXTGRD	1.01E-03	S WALL	LLI WALL	PANCREAS	ADRENALS	MARROW	2.14E-04
		EXTCLD	1.78E-07	S WALL	PANCREAS	LLI WALL	ADRENALS	MARROW	4.63E-08

APPENDIX B

Radionuclide Data and Assumptions Used In The Screening Analysis

The screening process described in Chapter 6 identifies those fuel cycle and by-product material facilities that are licensed for sufficiently large quantities of radioactive materials that, for the conditions assumed, a severe accident might pose a hazard to the general public. In the possession limit data base, a number of names and quantities for radionuclides or groups of radionuclides needed further definition in order to be included in the screening process. This appendix lists the detailed assumptions and data used in preparing the possession limit data base for use in the screening computer program.

In the data base, the licensed possession limit for a few radionuclides was listed on the license using mass units (kilograms, grams, etc) rather than activity units (curies). The screening program requires activity units for use with the unit dose estimates (rem/curie released). Specific activity conversion factors (curies/ kilogram) were supplied for these nuclides and are listed in Table B.1.

In the screening analysis, isotope and form-dependent release fractions were used (see Sections 2.3 and 6.3). For the "other" category of isotopes (nonvolatile solids), a smaller release fraction was used for material judged to be in a sealed source or encapsulated in an equivalent manner. The configuration terms and definitions assumed to be equivalent to a sealed source are listed in Table B.2.

In the data base, a number of terms were used to describe a material type that did not provide a unique specification of a single radioisotope. Some entries were simply element names, without any isotope(s) given. Others listed two isotopes or elements (e.g., BACE, CEPR, CF249/254, CU64/67, CEPR144, etc.). Neutron sources used a variety of names (e.g., AMBE, AM241/BE, PUBE, PU238BE, PU239BE). For each of these names for a material type, a single radioisotope was assigned for use as an equivalenced radionuclide in the screening analysis. These assignments are listed in Table B.3. The assigned radionuclide was selected from among those for which dose estimates had been prepared and are listed in Table 5.1.

A number of radionuclides occurred infrequently or only a few times in the license data base. For many of these, calculation of dose estimates using CRAC2 was not possible

Table B.1

Specific Activities of Radionuclides

Isotope	Specific Activity (Ci/kg)
AM241	3.44E+03
CF252	5.40E+05
NP237	7.06E-01
PU236	5.32E+05
PU238	1.72E+04
PU239	6.22E+01
PU240	2.28E+02
PU241	1.01E+05
PU242	3.93E+00
TH228	8.20E+05
TH232	1.10E-04
U232	2.14E+04
U233	9.66E+00
U234	6.27E+00
U235	2.17E-03
U236	6.48E-02
U238	3.37E-04

Table B.2

Configurations Considered to be Sealed Source or Equivalent

CSS	Combined Sealed Source
DBS DSS	Diffusion Bonded Sealed Source
ECR	Encapsulated Calibration or Reference Sources
ECS	Encased in Steel
EFC	Encapsulated Foils Contained in Nuclear Accident Dosimeters
ENC	Encapsulated
ENF	Encapsulated Foils
MSS	Metal Encased in Stainless Steel
PSZ	UO_2 Fuel Pellets Sealed in Stainless Steel or Zircalloy
SAB	Sealed Americium and Beryllium Neutron Sources
SCS	Sealed Calibration Source
SDS	Seeds
SED	Sealed Sources in Electron Captive Detectors
SFC	Sealed Fission Chambers
SFD	Sealed Fission Detectors
SFE	Sealed Fuel Elements
SGS	Sealed Gamma Sources
SIT	Sealed Ionization Tubes in Chambers
SLS	Self-Luminous Sites
SNB	Sealed Nuclear Batteries
SND	Sealed Neutron Detector
SNG	Sealed Neutron Generator Tubes
SNS	Sealed Neutron Source
SSS	Sealed Source Sets
SS	Sealed Source
SWM	Sealed Source in Completed LCD Watches and Modules

Table B.3

List of Assignments for Equivalent Radionuclides

MATERIAL TYPE (FROM LICENSE)	ASSIGNED NUCLIDE	MATERIAL TYPE (FROM LICENSE)	ASSIGNED NUCLIDE
AC227/BE	AC227	CO	CO60
ACR	I131	CSAMBE	AM241
AC	AC227	CSBA	CS134
AGR1	I131	CS131	CS136
AGR2	I131	CS	CS134
AGR4	I131	CU64/67	CU67
AGR5	I131	DU	U238
AG110	AG110M	ENT	TH232
AMBE	AM241	EU152/154	EU154
AMPUCM	AM241	EU	EU154
AM241/BE	AM241	FECD	CD113M
AM244	AM242	FE55/59	FE59
AM246	AM242	FE59/55	FE59
AM	AM241	GD162	GD153
AU195	AU198	GEGA	GA72
AU	AU198	HG197/203	HG203
BACE	CE144	HG197	HG203
BACS	CS134	HO166	HO166M
BALA	LA140	IN111/114	IN114M
BA/LA140	BA140	IN113M/111	IN111
BR77/82	BR77	IN113	IN113M
BR80	BR82	IN114	IN114M
CDAM	AM241	IR191M	IR192
CD109/HG203	CD109	I125/129	I125
CD113	CD113M	I125/131	I131
CD115M	CD113M	I125 OR 131	I131
CEPR144	CE144	I128	I132
CEPR	CE144	KR79	KR89
CE143	CE144	KR81	KR85
CF249/254	CF253	K43	K42
CF249	CF252	MFP	PU239
CF250	CF252	MG27	MG28
CF	CF252	MOTC99M	MO99
CL38	CL36	MOTC	MO99
CM247	CM245	MO99-TC99M	MO99
CM249	CM242	MO	MO99
CM250	CM245	NA24/22	NA22
CM	CM245	NA	NA22
CO61	CO58	NB92M	NB95
CO62	CO58	ND	ND147
CO63	CO58	NP234	NP239
CO64	CO58	NP235	NP239

Table B.3 (Continued)

List of Assignments for Equivalent Radionuclides

MATERIAL TYPE (FROM LICENSE)	ASSIGNED NUCLIDE	MATERIAL TYPE (FROM LICENSE)	ASSIGNED NUCLIDE
OSIR	IR192	TC	TC99
PM148	PM147	TE119M	TE127M
PO208	PO210	TE123M	TE127M
PO209	PO210	TE123	TE127M
PO218	PO210	THN	TH232
PO	PO210	THU	U238
PR147	PR144	TH225	TH227
PT183	PT193	TH229	TH230
PUBE	PU238	TH231	TH234
PUCS	PU239	TH233	TH234
PUI	PU239	TH	TH232
PUU	PU239	TM166	TM170
PUO2	PU239	TM171	TM170
PU237	PU236	TM172	TM170
PU238BE	PU238	TUE	PU239
PU238/239	PU238	UIR	U235
PU239BE	PU239	UND	U238
PU244	PU239	UTH	U238
PU	PU238	UUR	U235
RBKR	RB86	U232	U233
RB	RB86	U236	U234
RURH	RU103	U237	U234
RU97	RU103	U239	U234
SBBE	SB124	U	U238
SB	SB124	V49	V48
SCA	I131	W	W187
SCB	EU152	XE127	XE133M
SMAT	TH232	XE	XE133
SMA	TH232	ZN63	ZN65
SM153	SM151	ZN69	ZN65
SNIN	SN113	ZN	ZN65
SNM	PU239	ZRNB	ZR95
SN119	SN119M		
SN125	SN126		
SOM	TH232		
SRKR	SR90		
SRYB	SR90		
SRY90	SR90		
SRY	SR90		
SR	SR90		
TB161	TB160		
TC96	TC99M		

due to lack of supporting data (e.g., dose conversion factors). In order to make the initial screening as complete as possible, each of these nuclides was assigned to an equivalent radionuclide having a similar half-life, decay emissions and decay energies and for which the dose estimates are available (in Table 5.1). As an example, ^{244}Am with a 10 hour half-life and beta emission of 0.39 Mev was assigned as equivalent to ^{242}Am with a 16 hour half-life and a beta emission of 0.67 Mev; ^{242}Am appears in Table 5.1. The equivalence assignments are also included in Table B.3. The material type from the license file is listed in the first column and the assigned radionuclide from Table 5.1 in the second.

Two complex sources were listed in the data base, with the forms CSAM and CS137/PU238, and with quantities specified for each of the isotopes in the complex. These complex sources were assigned the CS137 and AM241 dose estimates, and the CS137 and PU238 dose estimates, respectively.

For nuclides with several possible clearance classes, the screening process used the class that had the highest specific dose estimate (rem/curie released values from Table 5.1). For uranium compounds, the Y class for insoluble compounds was used. For plutonium, the W class for soluble compounds was used.

A number of Part 40 and Part 70 licenses listed uranium material types with various degrees of enrichment of ^{235}U. For the screening analysis, four standardized enrichments were adopted and used:

Depleted Uranium (DU)

Natural Uranium (U)

LWR enriched Uranium $< 5\%\ ^{235}U$

Highly enriched Uranium $> 5\%\ ^{235}U$

Isotopic compositions and dose estimate calculations for a 1 kilogram release of each of these materials are listed in Table 5.6. For depleted uranium, ^{238}U can almost be used as a direct equivalent. For natural uranium, approximately one-half the dose is from the small faction of ^{234}U and the other half from the ^{238}U. For the LWR and highly enriched compositions, the dose estimates are dominated by the ^{234}U component.

Two terms appear in the Part 40 data base to describe mixtures of uranium and thorium: UTH and THU. Since the quantities associated with these material types used mass rather than activity units, these were assumed to be all

natural uranium, since the dose estimate per kg released is higher for uranium than thorium. If the material had been specified with an activity quantity, then thorium would be the proper (and conservative) equivalence.

The medical licenses included in Part 30 required special rules to define nuclides and possession limits for the various groups, as the license usually does not list such information. These definitions were derived from discussions with and information received from Mrs. Pat Vacca, Material Licensing Branch, USNRC, Washington, D.C.

Under Part 35 licenses for Human Use of By-product Materials, eight general groups are defined for medical applications. For almost all of the licenses using these group designations, the group designation is the material type, with the configuration and possession limit left blank. For these, a specific radionuclide and possession limit were assigned for use in the screening analysis. On a few of the licenses, a nuclide and/or a possession limit are listed in addition to the group designation. For these few, the license entries would take precedence over the assigned values.

Group I: Defines materials used in prepared radiopharmaceuticals for certain diagnostic studies involving measurements of uptake, dilution, and excretion. Radionuclide included in this group are ^{131}I, ^{125}I, ^{58}Co, ^{60}Co, ^{51}Cr, ^{59}Fe, and ^{99m}Tc. Of the isotopes included in this group, ^{131}I and ^{125}I would represent the largest potential radiological hazard. The radioiodines are received by the licensee in single vials of 2 mCi each, and the number of vials usually is limited to 10 vials at any one time. For the screening analysis, ^{131}I is the assigned radionuclide, with a quantity of 100 mCi.

Group II: Covers the use of prepared radiopharmaceuticals for diagnostic imaging and localization studies. Group II Radionuclides include ^{131}I, ^{125}I, ^{51}Cr, ^{198}Au, ^{197}Hg, ^{203}Hg, ^{75}Se, ^{85}Sr, ^{99m}Tc, ^{169}Yb and ^{113m}Yb. Again, the radioiodines represent the greatest potential hazard, and are received and stored as defined for Group I. As was done for Group I, a 100 mCi source of ^{131}I is assigned.

Group III: Licenses the use of generators and reagent kits for the preparation and use of radiopharmaceuticals containing by-product material for diagnostic studies. This group includes $^{99}Mo/^{99m}Tc$ generators, ^{99m}Tc as the pertechnetate and $^{113}Sn/^{113m}In$ generators. The tin generators are not distributed in the United States and were not used in the definitions for Group III. The $^{99}Mo/^{99m}Tc$ generators are limited to 2 Ci productions of pertechnetate. The assignments for the screening are 2 Ci of ^{99m}Tc and 2 Ci of ^{99}Mo.

Group IV: Includes the use of prepared radiopharmaceuticals for certain therapeutic uses that do not require hospitalization. Iodine-131 for use in the treatment of cardiac dysfunction is the principal nuclide in Group IV. Phosphorus-32 is also licensed under Group IV for some cancer treatments. However, it is not used extensively and only with few patients. Iodine-131 is usually administered in doses of 30 mCi or less per patient, with a total of 150-200 mCi on hand at any one time. For the screening analysis, a quantity of 500 mCi of ^{131}I was assigned.

Group V: Licenses the use of prepared radiopharmaceuticals for therapeutic uses that require hospitalization for purposes of radiation safety. Gold-198 for intracavity treatment of malignant effusions and ^{131}I for treatment of thyroid carcinoma are included in this group. Gold-198 for this use is not commercially available in the United States. The ^{131}I is administered in dosages of 30 mCi to 400 mCi from vials of 75-150 mCi each. The total unused storage of ^{131}I was estimated to be 500 mCi. Again, ^{131}I is the assigned radionuclide, with a quantity of 500 mCi.

Group VI: Covers the use of sources for irradiation of tumors. Sealed sources of ^{241}Am, ^{137}Cs, ^{60}Co, ^{198}Au, ^{125}I, ^{192}Ir, and ^{90}Sr are generally licensed under Group VI. The ^{241}Am sources would represent the greatest radiological hazard if material were released. Most of the ^{241}Am sealed neutron sources (~400 mCi each) are used in bone mineral analyzers and it was assumed that no licensee has more than two analyzers. Americium-241 was assigned as the nuclide for Group VI licenses, and with a quantity of 800 mCi. It is unlikely that material from these sources would become airborne in an accident and a release fraction 0.001 was used in determining the source term for the Group VI licenses.

GLM: For general medical licenses (GLM) the possession limits from the Code of Federal Regulations (10 CFR 35.31) are: 200 µCi of ^{131}I, 200 µCi of ^{125}I, 5 µCi of ^{58}Co, 5 µCi of ^{60}Co, and 200 µCi of ^{51}Cr. These isotopes and quantities were used if no possession limit quantity was specified. If a possession limit quantity was listed on a license but without a radionuclide, then ^{131}I was assigned as the radionuclide.

VIT: Licenses for vitro clinical uses (VIT) cover various radionuclides (^{125}I, ^{131}I, ^{14}C, ^{3}H, ^{59}Fe, ^{75}Se), but limit the total possession quantity to 200 µCi. Again, Iodine-131 has the greatest hazard potential for this group, and 200 µCi of ^{131}I was assigned for the screening.

For some medical licenses, certain configurations are sometimes used without a possession limit quantity being specified. Suitable quantities were defined for these configurations, based on the use and the number of treatments available at any given time. Table B.4 lists the radionuclides, configurations and assumed possession limit quantities. In the screening analysis, an assumed quantity from Table B.4 is used if none is listed in the data base.

General licenses (Type A, Type B, and Type C) are available under 10 CFR Part 33. Possession limit quantities for some 200 radionuclides are listed in Schedule A of Part 33.1. For the screening process, ^{129}I was selected as the radionuclide with the greatest potential dose hazard. For Type A and Type B licenses 0.1 Ci of ^{129}I was assigned for use in the screening. For Type C licenses, 0.01 Ci of ^{129}I was used, as specified in Column 2 of Schedule A.

The "any" category license is used to allow possession of a broad range of radionuclides, with an overall possession limit and under a single material type (as opposed to an exhaustive listing of possible nuclides.) Many forms of the "any" category were found in the license data base; these are listed in Table B.5. It was decided that the 10 radionuclides in the category with the highest specific dose estimates at a 100 m distance (from Table 5.1) would be representative of the radionuclides in that "any" category and would provide a reasonable estimate of the potential hazard. Lists of the radionuclides assigned to the various categories are presented in Table B.6. For some categories, up to 12 radionuclides are provided, in case one or more radionuclides are listed as an exception on the license. In the screening process, the first 10 from the list which are not otherwise listed as an exception are used.

However, a smaller number than 10 may be used for screening some "any" licenses depending on the possession limits. For some licenses, an individual limit (per isotope) and a total limit are specified (e.g., 10 mCi/500 mCi). For these, if the ratio of the total limit to the individual limit is greater than 10, then only the first 10 from the appropriate list in Table B.6 are used. If the ratio is less than 10, then only that number (rounded to the next whole integer) is used, but not less than one. A few licenses have a total quantity specified, but a zero for the individual nuclide limit (e.g., 0/10 Ci). For these material types, the single nuclide assignments in the bottom part of Table B.6 are used.

Table B.4

Medical Configurations

Radionuclide	Configuration	Assumed Possession Limit Quantity (mCi)
H3	DXG	100 mCi
C14	DIE	100
	TAB	100
P32	CCP	100
	COG	100
	SOL - Soluble phosphate as treatment for leukemia and bone metastases	50
S35	SLF	100
Cr51	CHR	10
	LBC	10
Co60	LUB	1
	NAC	100
Se75	SEL	1
Kr85	DSL	100
SR90	EYE - Eye Applicator	150
Tc99m	HSA	2000
	KIM	2000
	PHY	2000
	SUC - Sulfur colloid	2000
I125	DVP	100
	PPK	100
	SDS - Seeds for interstitial cancer treatment	1
	TRI	100
I129	THY	100
I131	ADI	100
	BFP	100
	CAR	500
	CSN	100
	HYP - Iodide for treatment of hyperthyroidism	500
	IHS	100
	LCN	100
	LUS	100
	MHS	100
	SDS - Seeds for interstitial cancer treatment	100
	TIF - Iodide for thyroid imaging	100
Au198	COL	200
Xe133	BFP - Gas for blood flow and pulmonary studies	2000

Table B.5

Definition of "ANY" Categories

Any by-product material	A
"Any by-product material between Atomic Numbers...	
... 1 and 83 (inclusive)"	A1
... 2 and 83 (inclusive)"	A2
... 3 and 83 (inclusive)"	A3
... 1 and 84 (inclusive)"	A4
... 85 and 103"	A5
... 85 and 89, inclusive; 91, 93, and 95 to 100, inclusive	A6
... 85 and 89, inclusive, with half-life less than 14.3 days	A7L14.3D
... 3 and 84	A34
... 1 and 85"	A85
... 90 and 97, except Curium 248 and Curium 250	A90
... 1 and 91"	A91
... 84 and 92	A92
... 84 and 94"	A94
... 84 and 96	A96
... 84 and 98"	A98
... 89 and 98	A89
... 1 and 103"	A03
... 1 and 83, except alpha particle emitters"	AXA
... 1 and 83, inclusive except Iodine 129"	A1XI129
... 1 and 83, inclusive except Iodine 131"	A1XI131
... 1 and 83, inclusive except Silicon	A1XSI
... 1 and 83, inclusive except Strontium and Iodine	A1XSRI
... 3 and 83, with 1/2 lives less than 48 hours	A3L48H
... 3 and 83, with 1/2 lives greater than 48 hours, less than 60 hours (substitute "m", "s" or "w" for minutes, seconds, or weeks as appropriate)	A3G48HL60H

Table B.6

Radionuclides Used in the "ANY" Categories
for the Screening Analysis

Category
A83, A85, A03, A, A89, A90, A94, A95, A96, A98

TH232	CM248	U232	PU239	AM241	AM243
PU240	PU242	AM242M	NP237	PU238	CM245

Category
A1, A2, A3, A1XSI, A1G20H, A3G2W, A3L6H, A3G20H, A3L48H, A3XSR90

CD113M	I129	SR90	HO166M	RU106	NB94
CE144	EU154	ZR93	I131	I125	CO60

Category
A4, A5, A34

PO210	CD113M	I129	SR90	HO166M	RU106
NB94	CE144	EU154	ZR93	I131	I125
CO60					

Category
AXA, A3XALPHA

CD113M	I129	SR90	HO166M	RU106	NB94
CE144	EU154	ZR93	I131	I125	CO60

Category
A1XI129

CD113M	SR90	HO166M	RU106	NB94	CE144
EU154	ZR93	I131	I125	CO60	

Category
A1XI

CD113M	SR90	HO166M	RU106	NB94	CE144
EU154	ZR93	CO60			

Category
A1XSRI

CD113M	HO166M	RU106	NB94	CE144	EU154
ZR93	CO60				

Table B.6 (Continued)

Radionuclides Used in the "ANY" Categories
for the Screening Analysis

Category A3G168H	Category A6	Category A3G40ML20H, A1G40ML20H	
I126	AM241	I135	
Category A3L168H,A3L2WK	**Category A3L40M,A1L40M**	**Category A7L14.3D**	**Category A91**
I131	KR89	AC228	TH232

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13. ABSTRACT (200 words or less)

This report summarizes work done for the U.S. Nuclear Regulatory Commission as part of a program considering the need for and appropriate level of emergency response planning at fuel cycle and by-product material facilities. The purpose is to (1) provide a base of technical information for identifying and ranking those facilities for which the need for emergency response planning and preparedness should be further considered, and (2) perform an initial screening of licenses issued by NRC. A data base containing the radionuclide possession limits for each license was developed. Dose estimates for a unit (1 curie) release of each of the radionuclides in the data base were calculated. To account for the variability in weather, distributions of doses were estimated for a full range of meteorological conditions. As requested by NRC, doses at the 99th percentile of the distribution were used. An initial screening analysis was performed for the approximately 9400+ licenses by comparing the estimated 99th percentile dose for a postulated release of a fraction of the licensed possession limit to the dose levels suggested in the Environmental Protection Agency's Protective Action Guides.

Using relatively conservative assumptions in the screening analysis, all but at most a few hundred licenses were found to have estimated doses below the Protective Action Guide levels. The few hundred identified in this initial screening should be further evaluated using realistic assumptions and site-specific information to establish the need for, appropriate level and extent of, and potential effectiveness of emergency response planning and preparedness beyond that currently required.

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